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EXPLORATORY STUDY OF LEAN CONSTRUCTION: ASSESSMENT OF LEAN IMPLEMENTATION

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Exploratory Study of Lean Construction: Assessment of Lean Implementation

by

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Dedication

"Now to him who is able to do immeasurably more than all we ask or imagine,

according to his power that is at work within us, …" (Ephesians 3:20)

To my Lord,

my parents,

my wife, Jihee Choi,

my daughter and son, Yeojin and Seokjin

with love and appreciation

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Exploratory Study of Lean Construction:
Assessment of Lean Implementation

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Since Lean Construction has been introduced as a new management approach to improve productivity in the construction industry, much research is in progress to develop lean concepts and principles for better implementation and to get results of the successful adaptation of lean ideas from manufacturing for application in the construction industry. Currently, several construction companies in the USA are starting to implement lean construction with nebulous hopes of obtaining better results from their current projects than from past projects not employing lean construction. There are many difficulties in adopting lean concepts and systems into construction projects and implementing lean construction in real construction sites. Thus, there are demands to share information how other companies implement lean construction, to identify the benefits and barriers of lean implementation in the construction fields, and finally

to improve their lean implementation. This study was the first exploratory study to assess lean construction implementation on overall projects. The case studies carried out the examination of the mutual relationships of lean planning systems, organization structure, attitudes of project participants and company strategy which played major influences on successful lean implementation.

In conclusion, the study found that lean construction was efficient in managing project with lean tools, and was enough effective to improve other project successful factors associated with project accomplishment. Lean construction emphasized and focused on improvement of relationships among project participants. The study found that lean construction was made up of lean tools, human resources, and company strategies. Thus, successful lean implementation was observed when these lean tools, human resources, and company project strategies were well-combined and mutually supported.

Even though lean construction still stood on the bridge crossing from current practice to lean practice, it is the researcher's conviction that lean construction would be successfully adapted to the construction industry in the near future and would be recognized as an effective management innovation. This study is anticipated to be a framework for future studies in the academic field and for future construction projects employing lean construction.

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Chapter 1: Introduction

1.1 INTRODUCTION

Lean construction has been introduced as a new management approach to improve productivity in the construction industry. Much research is in progress to develop lean concepts and principles for better implementation and to get results of the successful adaptation of lean ideas from manufacturing for application in the construction industry. However, since the start of work on the lean construction theory and methods in 1992, the construction companies that employ Lean Construction have been struggling to transform their current forms of project management into the lean management approach. The two management approaches, traditional and lean, have fundamental differences of the lean "pull" concept as opposed to the traditional "push" concept. Furthermore, the performance measurement method "Percent Plan Complete (PPC)" in lean construction is different from traditional measurements, including "Work Breakdown Structure (WBS)", "Critical Path Method (CPM)" and "Earned Value".

Most construction companies in the U.S. that are starting to implement lean construction hope to achieve better results from their current projects than from past projects not employing lean construction. Several studies assess lean implementation and focus on the process of each construction activity, but few empirical studies assess lean implementation on the overall project. Companies need success stories to encourage them to employ lean construction into their work processes. Adopting lean concepts and systems into construction projects is difficult. It is a new philosophy which should make construction companies hesitant to employ it, and companies are not sure that lean concepts will produce benefits.

This study will carry out case studies to assess current lean construction projects with the objective to find out how effectively and to what extent lean construction is being adapted by the construction industry. Furthermore, the benefits and barriers associated with lean implementation, the opportunities for improvement, and the effects that lean construction has on human resources and overall projects will be evaluated. This study should encourage other construction companies to consider lean construction in the future.

1.2 SCOPE AND OBJECTIVES

The scope of this research assesses how effectively lean construction has been adapted in the U.S. construction industry. The assessment of how properly lean construction is implemented in real construction sites and the evaluation of the attitudes of human resources toward lean construction will be examined as well. Each case study will carry out the examination of the mutual relationships of organization, attitude and contract to achieve a highly successful implementation of lean construction. The detailed objectives to satisfy the scope of this study are as follows:

- Assess the attitude and comprehension of each level of an organization toward lean ideas.

    - Assess lean construction from the viewpoint of the various project participants: owner, general contractor and subcontractors.
    - Assess beneficial effects of lean principles on human resources.
- Assess the lean implementation on real construction sites.
    - Evaluate which lean concepts and systems are applied to the sites.
    - Assess whether lean principles and systems are properly implemented on site.
    - Identify benefits and barriers associated with lean implementation.
    - Identify opportunities for improvement of lean implementation.
- Assess contractual effects of implementing lean construction.

1.3 RESEARCH HYPOTHESIS

This study assumes that lean implementation can be assessed through the evaluation of the lean implementation success factors: planning systems, organization, project participants' attitudes, and contracts. The study will test the hypothesis that if the four factors of planning systems, organization, attitudes, and contracts are mutually and effectively combined, lean construction will be successfully implemented.

1.4 LIMITATIONS OF RESEARCH

A major limitation to the scope of this study is collecting sample data. Most companies have just begun to implement lean, so it is difficult to find companies that employ lean construction. Furthermore, it may be premature for companies to begin sharing data related to human factors. Some companies reject requests to complete surveys in order to hide the chaotic situation at the beginning stages of implementation. It is difficult to identify individuals who fully understand lean construction and who are willing to answer the survey as well. Some companies are reluctant to share information due to competitiveness. Sometimes the owner of a construction firm wants to keep information confidential.

This study is not research proposed by any institutes or academic research centers, so it was difficult for the researcher to obtain sensitive and detailed data relative to project cost and schedule. Most projects are now under way and could not provide final actual project costs and schedules which can be compared to the budgeted costs and schedules.

Many companies have recently applied the Last Planner System, a decentralized system that narrows uncertainty as the time for work approaches and builds judgment through rapid learning (Ballard and Howell, 1997) to obtain more detailed planning to improve their current performance. This research, however, will try to find as many subjects as possible associated with lean implementation.

Based on the previously mentioned considerations, the in-depth case study approach has been chosen for the research methodology to assess lean construction, its implementation, and the attitudes of human factors toward lean construction. Questionnaire surveys provide quantitative data and visual statistical results, but may have problems with the lack of significant sample data and the difficulty in selecting people who are reliable and can fully answer the questionnaires. Thus, this study was mainly performed by face-to-face interviews with five or six simple questionnaires. This allowed for broad and detailed findings.

The survey companies are selected from the membership of the Lean Construction Institute (LCI). To date, few companies have been involved in the LCI. Currently, 13 companies are members (www.leanconstruction.org, February 4, 2002) and among them only four or five companies are at the level of the general contractor. Others are subcontractor and consultant companies. With this narrow sampling, the results of this study may be indicative only of the companies involved, regardless of the number of construction projects. However, lean construction is anticipated to be widely used by more prominent companies in the near future and should be verified as a better management approach in the construction industry.

1.5 ORGANIZATION OF THE STUDY

This study consists of six chapters. The first chapter consists of an introduction, the scope and objectives of the study, the hypothesis of the study, and limitations of the study. After this introductory chapter, later chapters will discuss the following material:

Chapter 2 will review the background of the study through a literature review. The methodologies used for gathering detailed information for this study are outlined in Chapter 3. Anticipated findings from case studies will also be presented, including the questionnaire and face-to-face interview design. The observations and findings of the simple questionnaire surveys and face-to-face interviews from the case studies are summarized in Chapter 4. The fifth chapter discusses the findings of case studies. Finally, in Chapter 6, an overall summary of the case studies will be discussed and important findings from the study will be reiterated as conclusions. Opportunities for improvement will be suggested, and further areas of research will be outlined as well.

Chapter 2: Literature Review

Lean construction may be one of the most complex and confusing philosophies or theories to understand for lean beginners who are already familiar with current project management practices. However, if one has enthusiasm and is ready to accept the lean ideas, it is easy to find out how it works and what it means. As mentioned in Chapter 1, lean construction is a new form of project management. As a result, one should not anticipate the same procedures and results as shown in the current practices. Lean principles and concepts must be understood and then applied them to implement lean systems. Lean practices enable projects to be completed on time and under budget. This chapter describes the background of lean construction, primarily drawing from on-line conference papers, white papers, and publications of the LCI and the International Group of Lean Construction (IGLC).

2.1 History of Lean Production

"Lean production," first coined by John Krafcik of the MIT International Motor Vehicle Program, describes a form of manufacturing that uses less of everything as compared to mass production: less human effort in the factory, manufacturing space, investment in tools, engineering hours, and inventory warehouse (Womack, Jones and Roos, 1990). Ohno and Shingo, Japanese engineers for the Toyota Auto Company, developed the Toyota Production System (TPS) that followed the flow-based production management of Henry Ford that included the merits of craft production and mass production. The goals of TPS were customer satisfaction, zero inventory, zero waste and perfection. In other words, lean ideals would meet the requirements of a unique customer, deliver the product instantly, and maintain no inventory. To achieve those goals, two major techniques were performed. The first was decreasing and consequently depleting inventory, and the other was accepting the pull-type production system. Those techniques fulfilled important goals of the TPS: zero waste and efficiency of production. Ohno and Shingo defined waste as follows (Womack and Jones, 1996):

- Defect in products
- Overproduction of goods not needed
- Inventories of goods awaiting further processing or consumption
- Unnecessary processing
- Unnecessary movement of people
- Unnecessary transport of goods
- Waiting by employees or process equipment to finish work or for on an upstream activity to be completed
- Design of goods/services that fail to meet user needs

Since 1991, a research team including James Womack theoretically defined and introduced the Lean Production System (LPS) by suggesting the TPS as a successful sample model. The LPS focused on the lean approach formulated in the book "Lean Thinking" by Womack and Jones (1984). The guiding principles of lean thinking are:

- Specify value by product.
- Identify the value stream.

- Make product flow processes.
- Use a pull logistic.
- Pursue perfection – custom product, zero time delivery and nothing in stores.

However, Womack and Jones focused on reducing cost without considering the concept of generating value. This might be a valid strategy when looking upon the mass producing industry, but for one-of-a-kind productions such as construction projects, was a serious mistake. The validity of Womack and Jones' formulation of lean principles was challenged by Glenn Ballard, who formulated the objectives as:

- Deliver the product while maximizing value by giving the customer what they need and when they need it.
- Minimize waste by eliminating anything not needed for delivering value.
- Pursue perfection by never stopping to strive to better achieve the lean ideal.

These objectives were further elaborated upon by Ballard and Howell in 2001 in a number of principles for implementation of lean principles not only in construction, but in any project delivery process.

Bertelsen, a member of the Danish Society of Consulting Engineers, in his report, "Bridging the Gap towards an Understanding of Lean Project Management" (2001), insisted that Ballard's formulation of the objectives was more precise and covered more aspects than Womack and Jones', but observed that it omitted a very important point: ongoing improvement. He proposed that lean principles should be: While delivering the project, an ongoing effort should be made to maximize the value and minimize the waste.

2.2 LEAN CONSTRUCTION

Lean construction accepts Ohno's production system design criteria as a standard of perfection. Generally, the construction industry has rejected many ideas from manufacturing because of the belief that construction is different. Manufacturers make parts that go into products, but the design and construction of unique and complex projects in highly uncertain environments under great time and schedule pressure is fundamentally different. The movement to apply the concepts of LPS to the construction industry was started by several researchers. Koskela (1992) claimed that the traditional conversion production system would be required to change to the new lean concept of the flow production system, and this would improve efficiency in the construction industry. Since then, much research on lean construction has been conducted. The current institutes focusing on the lean ideas are the International Group of Lean Construction (IGLC) founded in 1993 and the Lean Construction Institute (LCI) founded in 1997.

Lean construction is a production management-based project delivery system emphasizing the reliable and speedy delivery of value. It challenges the generally accepted belief of a trade-off between time, cost and quality. Since 1993, two major lines of thinking have governed the work on lean construction. One is Koskela's Transformation-Flow-Value concept and the other is Ballard and Howell's Last Planner methods of production control. To date most U.S.

construction companies have followed the Last Planner methods to improve performance. In addition to the Last Planner methods, the Lean Construction Institute has developed another way to design and build capital facilities by reforming the management of production. (http://www.leanconstruction.org) The LCI calls that new way the Lean Project Delivery System, LPDS. It applies principles pioneered in manufacturing to construction. LPDS tools facilitate planning and control, maximizing value and minimizing waste throughout the construction process. Its model consists of eleven modules, organized into five interconnecting triads or phases extending from project definition to design to supply, then assembly and use. The LPDS also has a production control module and a work structuring module, both conceived to extend through all project phases, and learning loops, which is a post-occupancy evaluation module that links the end of one project to the beginning of the next. Learning is a process that occurs in cycles, thus the learning loop is incorporated at every level, and dedicated to rapid system adjustment. Figure 2.1 presents the diagram of LPDS developed by the LCI. The LCI also defined the concepts and principles of lean construction as follows:

> Lean construction is a new way to design and build capital facilities. Lean theory, principles and techniques, taken together, provide the foundation for a new form of project management. (http://www.leanconstruction.org)

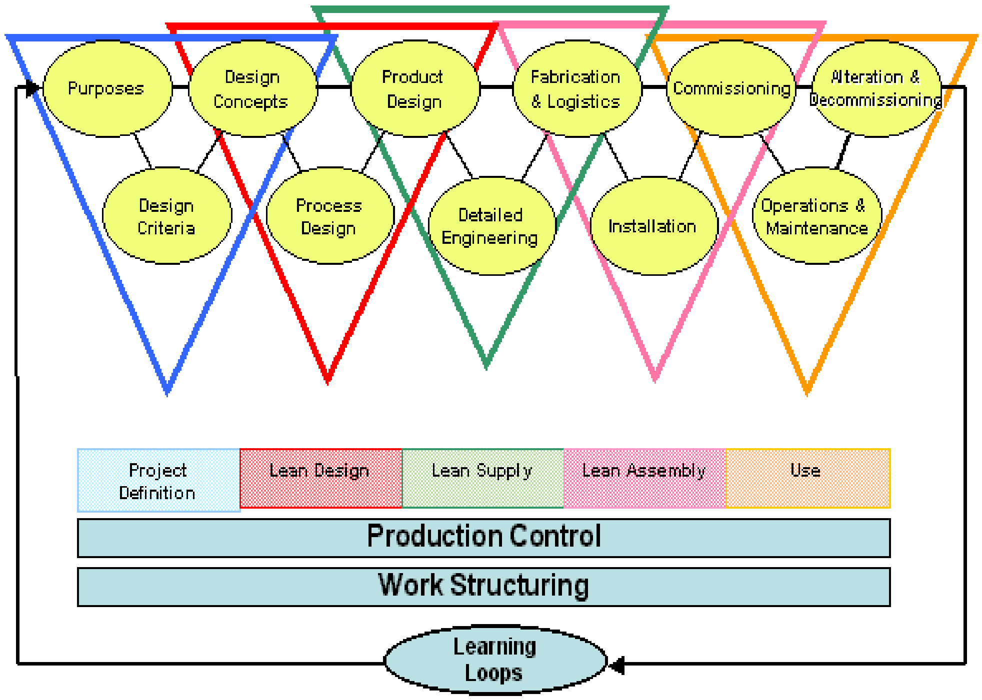

Figure 2.1. Lean Project Delivery System

Koskela (1992) introduced some important concepts and established principles about the production function of construction. These concepts and principles envision construction as a net of cycling production flows that have conversion and non-conversion activities, as well as activities that add and activities that do not add value to the final product or sub-product. Koskela (1992 and 1999) believes that production activity consists of four consecutive processes: moving, waiting, processing and inspection. He categorized all construction production processes into these four stages, and furthermore determined if each stage created value. Only the processing was determined as value adding in the construction production process. To optimize the construction production process, non-value adding stages such as moving, waiting and inspection had to be reduced, while the efficiency of the value adding stage was maximized. To implement this and improve processing, Ballard (1999) suggested several production techniques as follows:

- Stop the line whenever defects are recognized.
- Procure materials by a pull-type production system.
- Reduce lead time by increasing flexibility against variation.
- Design pre-planning to prevent delay and to provide a buffer.
- Apply production system process transparency to decentralize decision making.

2.3 LEAN VERSUS TRADITIONAL

The Lean Construction Institute (LCI Seminar, 2002) describes how current projects are to be managed and defines the project management as follows:

- Determine client requirements and design to meet them. Align design to quality, schedule, and budget limits.
- Manage the project by breaking it into pieces, estimating duration and resource requirements for each piece, and then put the pieces in a logical order with Critical Path Method (CPM).
- Assign or contract for each piece, give start notice and monitor each piece to assure it meets safety, quality, schedule and cost standards. Take action on negative variance from standards.
- Coordinate using the master schedule and weekly meetings.

- Cost may be reduced by productivity improvement. Duration may be reduced by speeding each piece or changing logic. Quality and safety get better with inspection and enforcement.

Traditional construction is too activity centered, control begins with tracking cost and schedule, and efforts to improve productivity lead to unreliable work flow, further reducing project performance. Protecting activities leads to adversarial relations and planning systems cannot coordinate the work between crews. Table 2.1 provides a comparison of the differences between lean construction and traditional construction.

Major differences between lean construction and traditional forms of project management include control, performance optimization, scheduling viewpoint, production system and process, performance measurement and customer satisfaction. The definition of control in traditional construction is monitoring against schedule and budget projections, while lean construction defines control as causing events to conform to plan. Traditional construction pursues the optimization of a specific activity, while lean construction optimizes the entire project. The most fundamental difference between traditional and lean can be found in scheduling. In scheduling, lean has the "pull" work schedule as opposed to the "push" schedule of traditional construction. Pull initiates the delivery of input based on the readiness of the process into which the resources will enter for transformation into outputs. Push releases materials, information, or directives possibly according to a plan, but irrespective of whether or not the downstream process is ready to process them. According to Hopp and Spearman

(1996), a push system schedules the release of work based on demand, while a pull system authorizes the release of work based on system status.

Table 2.1. Comparison of Lean and Traditional (LCI Seminar, 2002)

Lean Construction	Traditional Construction
Control	
Causing events to conform to plan – Steering	Monitoring against schedule and budget projections – Tracking
Optimization	
The entire project	A specific activity
Scheduling Viewpoint	
• "PULL" work schedule • Based on when its completion is required by a successor activity	• "PUSH" work schedule • Based on emphasizing required start dates for activities
Production System	
Flow production system	Conversion production system
Production Process	
Effectiveness	Efficiency
Performance Measurement	
Percent Plan Complete (PPC)	WBS, CPM, Earned Value
Customer Satisfaction	
Successor process satisfaction	Owner or final consumer satisfaction
Planning	
Learning	Knowing
Uncertainty	
Internal	External
Coordination	
Keeping a promise	Following orders
Goal of Supervision	
Reduce variation & Manage flow	Point speed & Productivity

Koskela, in his report "On the Agenda of Design Management" (IGLC 98), defined the traditional conversion production system as a task management approach. The project is a series of activities, which converts inputs to outputs. The project is composed of a hierarchy of sequentially dependent activities. The tools used for the conversion production systems are the Work Breakdown Structure (WBS), Critical Path Method (CPM) and organization charts. Koskela claims that the flow production system assures that the unnecessary is done as little as possible. The goal is to eliminate waste (non-value adding actions) by organizing interdependence, improving reliability, reducing uncertainty, and integrating production management.

The lean construction emphasizes effectiveness measured by cycle-time, defection rate, variation and reliability, and completion of planned work per week while traditional construction measures productivity to obtain efficiency. For measurement, lean uses the Percent Plan Complete (PPC), while traditional construction measures performance with WBS, CPM, and Earned Value.

The customer in traditional construction usually is defined as the owner or final consumer. However, in lean construction, the customer is the successor process. The predecessor has to fulfill the requirements needed by the successor process. In addition, coordinating action through pulling and continuous flow and decentralizing (Ballard and Howell, 1997) is paramount, as opposed to the traditional schedule-driven push with its "over-reliance on central authority" (Howell, 1999) and project schedules that manage resources and coordination. Decentralization means providing project participants with information on the state of the production systems and empowering them to take action without orders from upper level management.

Figures 2.2 and 2.3 identify the type of work flow represented in traditional and lean production management. Lean production management has fluency in work flow, while traditional project management has segmented work flow. The segments in traditional management produce the lack of a common language, lack of production knowledge, lack of team commitment, and disregard for variability. On the other hand the lean management can build reliability, manage work flow, improve the production management system, and obtain collaborative team commitment.

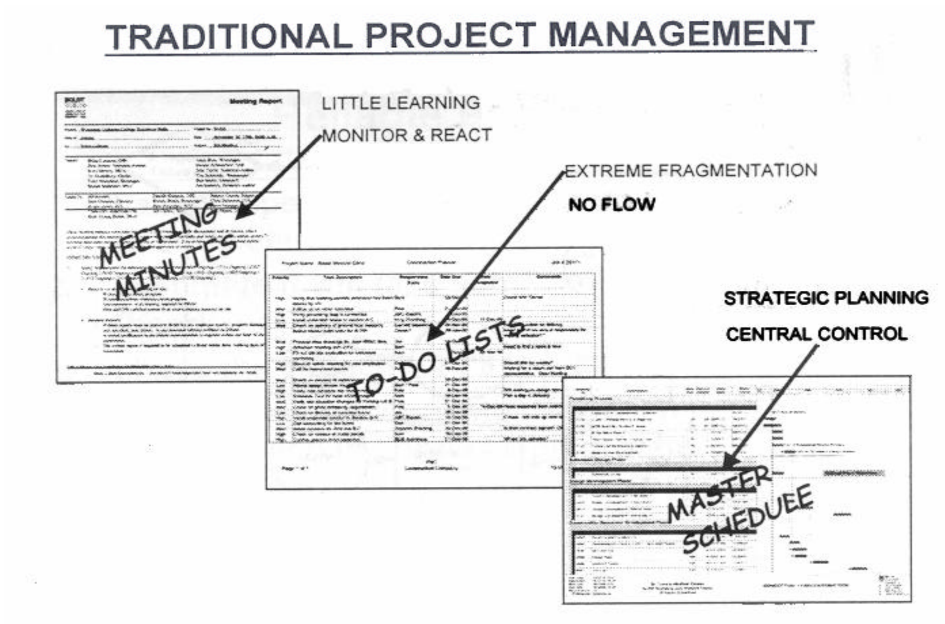

Figure 2.2. Work Flow of Traditional Project Management (LCI Seminar, 2002)

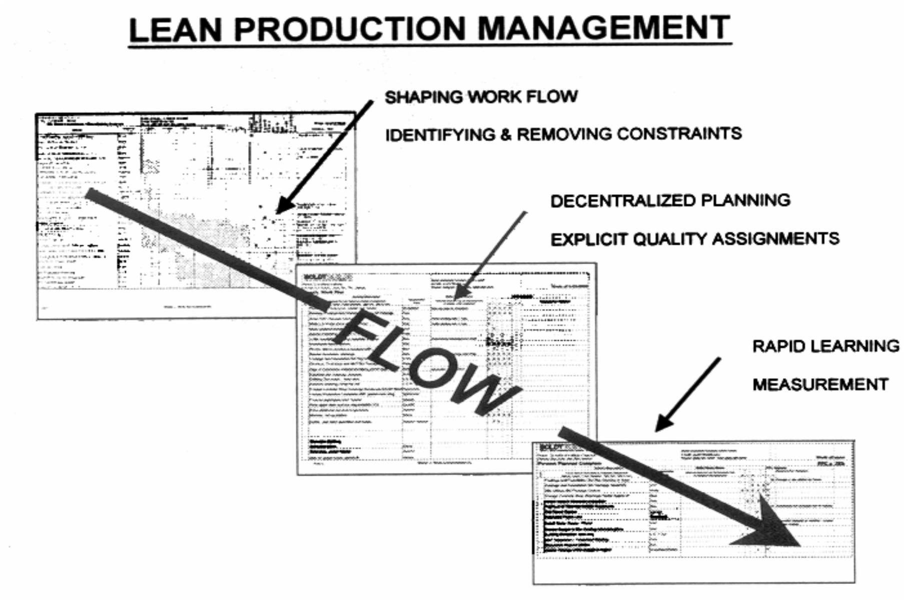

Figure 2.3. Work Flow of Lean Production Management (LCI Seminar, 2002)

Through planning, learning is obtained to prevent further repetitive failure. Planning is no longer just knowing.

Lean construction considers uncertainty as caused by internal factors rather than external factors that traditional practice identifies. Thus, the goals of supervision in lean construction are focused on the reduction of variations from internal factors and managing flow.

"Keeping A Promise" is the emphasis in lean implementation. The passive attitudes towards coordination such as "Following Orders" have changed to the active attitude in lean construction. The expectation of keeping a promise among project participants is anticipated to improve coordination and commitments.

2.4 ESSENTIAL FOUNDATIONS FOR LEAN CONSTRUCTION

As shown in Figure 2.1, work structuring, production control and learning loops are each single modules within the Lean Project Delivery System (LPDS). They are essential features for successful lean implementation. Two games, the "Dice Game" and the "Airplane Game" are used to strengthen project participants understanding of the concepts and principles of lean construction, and effectively support its two essential foundations: production control and work structuring.

For ongoing improvement while delivering the project, the network of learning (feedback) loops and the associated culture of learning are essential parts of the system and are stressed as well.

2.4.1 Production Control

Production control consists of Work Flow Control and Production Unit Control. The current construction industry seems to prefer speed rather than reliability of work flow. This is a fundamental error that lean construction will prevent: that is, crews that work out of sequence due to other crews going as a fast as possible. That causes disruption for the entire project. However, in lean thinking, reliability is emphasized to reduce workflow variability. It can improve total system performance, make project outcomes more predictable, simplify coordination, and reveal new opportunities for improvement. It ignores speed and productivity since throughput can validate its effectiveness. Consequently, the strategy of lean construction is to reduce variation, then go for speed to increase throughput. There are several games that are used to demonstrate the practical implications of lean construction concepts such as the impact of uncertainty and multitasking.

2.4.1.1 Dice Game

The “Dice Game,” suggested by the LCI to introduce lean construction, shows the relationship between speed and reliability. This game has been used to demonstrate the impact of uncertainty on the production rate of a simple project in a classroom environment. The game, introduced in the IGLC report (Luis et al. 1999), assumes that several different activities all have the same production rate, with an associated degree of uncertainty. The uncertainty in the production rates is represented by the roll of a die that has two values on each of its faces, representing the variability in the production rate. For instance, if the average production rate is 5, the die might have the following values on its faces: 5-5, 6-4, 7-3, 8-2, 9-1, and 10-0. Every roll will yield an expected production rate of 5 but with different variability. To play the game, the participants in the training session are organized into teams of a size equal to the number of activities: generally 5 team members per team. Each team is assigned a different type of dice with the goal of having at least one team for each type of variability. The game consists of carrying out a project that comprises 100 production units; coins, blocks, or other objects can represent the units. Each member of a team represents an activity and he/she will be responsible for managing the productivity of that activity. At the beginning of the game the 100 units will be stored next to the member of the team representing the first activity in the sequence. The first member of the team then will roll the die and will pass the number of units obtained from the experiment to the storage next to the following activity in the sequence. The following member of the team will then roll the die and pass on to the next activity the minimum of either the number of units indicated by the die or the units available in storage from the previous activity. The same procedure is applied in each step for the subsequent activities, and the members of the team repeat the process in turns until all the units are passed through the final activity. This indicates the completion of the project. During the game each member of the team will keep a record of the productivity obtained in each step by drawing the progress for the assigned activity in a "Line of Balance" type graph. The final drawings show the complete record of the project and allow comparison of different characteristics of the project such as productivity rates, completion dates, interferences between activities for the different variability. The goal of this game is focusing on reduction of uncertainty rather than on increasing production rates. This game also can be simulated using @RISK (1997) software designed to perform risk analysis using spreadsheets.

Figure 2.4 illustrates the flow variation and project outcomes. The team that rolls the die and gets 9 and 1, as shown in Figure 2.4, gets a big difference between the worst and best. The project can be completed earlier than other teams, but simultaneously, it can be finished later than others. It proves the uncertainty and risks of construction. In case the dice has 6 and 4, the difference between the worst and best is more narrow. The project should be completed in the anticipated time period if the variation can decrease. It shows that the less variation exists, the higher reliability occurs. Consequently, lean construction recommends reducing variability rather than going for speed. Reducing variations (uncertainties) systemically can reduce waste and increase project speed.

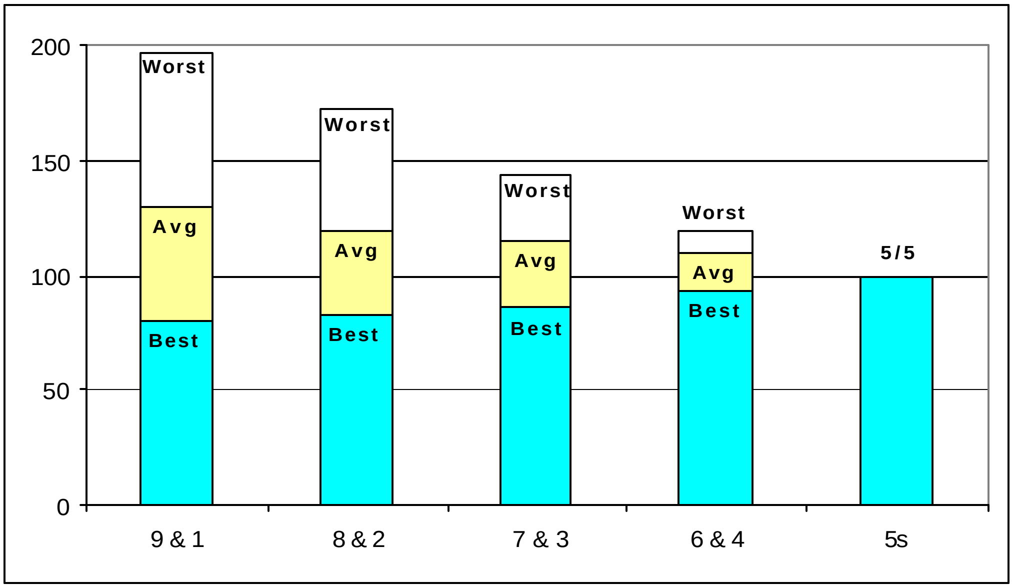

Figure 2.4. Flow Variation and Project Outcomes (LCI Seminar, 2002)

Figure 2.5 presents the relationship among variability, lead time and capacity utilization. The Y axis indicates wait time and the X axis represents capacity utilization. On the curve, the more capacity utilization, the more lead time is needed. For instance, once the utilization of the road in rush-hour increases, the wait time of traffic on it increases.

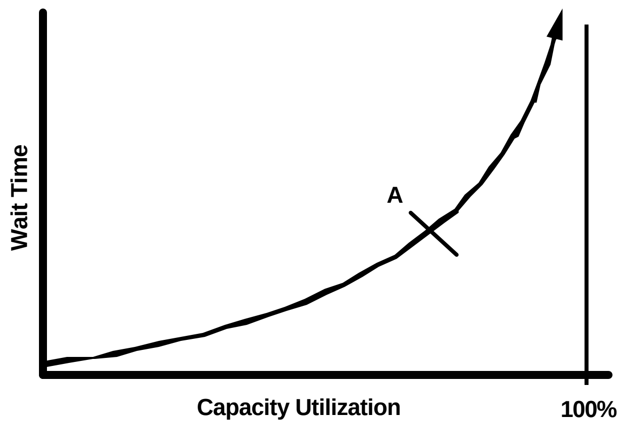

Figure 2.5. Variability, Lead Time, & Capacity Utilization (LCI Seminar, 2002)

The LCI insists that a project should make the curve more flat along the X axis by reducing variability and increasing the percent plan complete (PPC) percentage. In this case, the project can obtain higher capacity utilization at the same target waste time. Figure 2.6 illustrates the impact of variability, PPC and capacity utilization (LCI Seminar, 2002).

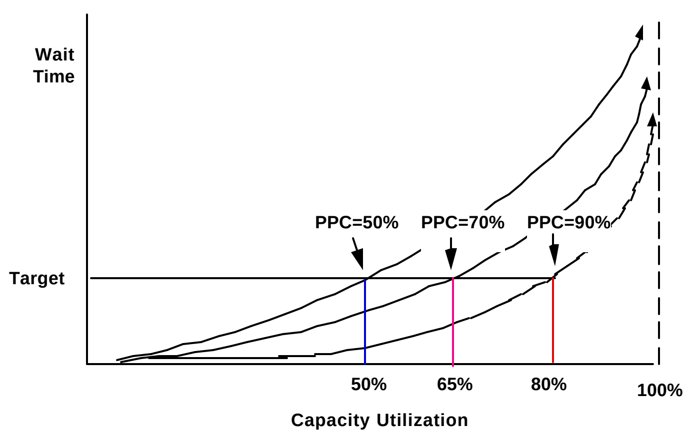

Figure 2.6. Impact of Variability, and PPC & Capacity Utilization (LCI Seminar, 2002)

2.4.1.2 *STABILIZATION OF WORK FLOW*

According to the lean construction glossary defined by the LCI, "the work flow is the movement of information and materials through a network of production units, each of which processes them before releasing to those downstream." Under lean construction, stabilizing work flow and improving its reliability is an important and required task to get successful achievement of the LPDS.

For the stabilization of work flow, backlog [1], shielding [2] and transparency are required. The backlog makes it possible to match labor and labor-related resources such as tools, equipment and temporary facilities. Shielding occurs at the level of the Last Planner commitment. They will be discussed later. The benefits of shielding are that expectations can be met. At the foremen and crew level, confusion and ambiguity decrease, and non-productive time falls such as waiting, hunting for something to do, rework and moving to alternative work without completing the planned work in that week. Lean construction emphasizes decentralization, meaning low level management can have the authority to make a decision for its own work. To give authority to low level management, transparency is required. Transparency can be obtained by reducing the interdependence between productive units, using visual devices, making the process directly observable, incorporating information, and keeping a clean and orderly workplace.

The stabilization of work flow can fail when direct workers inherit uncertainty and variation of workflow and there is non-productive time and de-motivated workforces. Most problems usually occur in the quality of planning. To prevent these problems, there are three solutions: educate the planner, improve planning, and clarify and modify directions (orders). Obstacles that prevent the stabilization of work flow are identified as follows: lack of information, lack of materials, low workforce utilization, poor planning, no on-time deliveries, no matching of labor to resource, and rework.

2.4.1.3 RELIABILITY OF WORK FLOW

Improving work flow reliability is important for the productivity of linked production units, and consequently for project cost and duration (Ballard, 1999). One measure of work flow reliability is Percent Plan Complete (PPC). Four actions are recommended to improve PPC and work flow reliability. The first is full empowerment of the last planners to refuse assignments that do not conform to quality criteria. The second is further improvement in definition by using "First Run Studies in construction and Activity Definition Models in design" (Ballard, 1999). The third is a consistent analysis and action on reasons for failing to complete assignments, and the fourth is adopting a sizing criterion for assignments that consistently demand less output from production units than their estimated average capacity in order to accommodate variability.

2.4.1.4 LAST PLANNER SYSTEM

The Last Planner system is based on a tradition planning system, Figure 2.7, but one more step is added and emphasized. That process is the Last Planning Process and is performed by field foremen. By adding this process, the condition of “SHOULD-CAN-WILL-DID” is implemented. Figure 2.8 presents the diagram of last planner (Ballard and Howell, 1997).

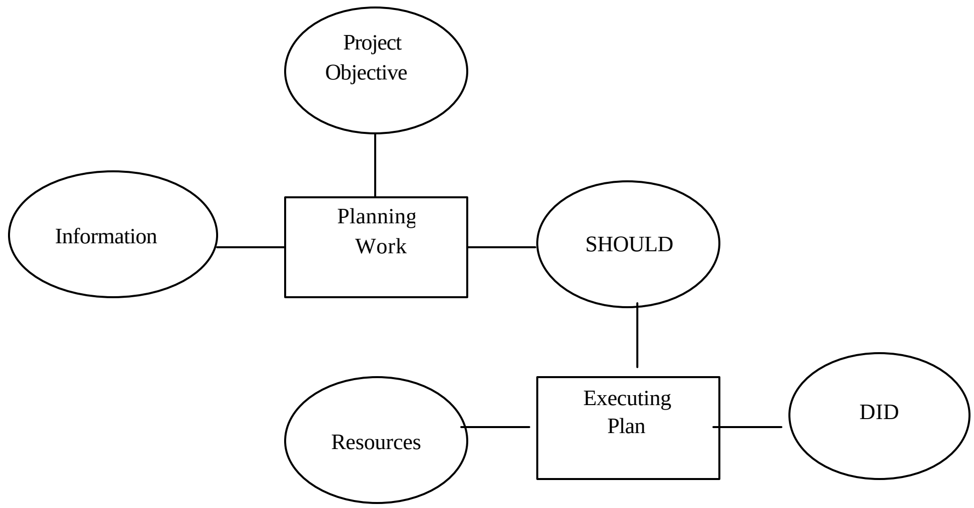

Figure 2.7. Traditional Push Planning System (Ballard and Howell, 1997)

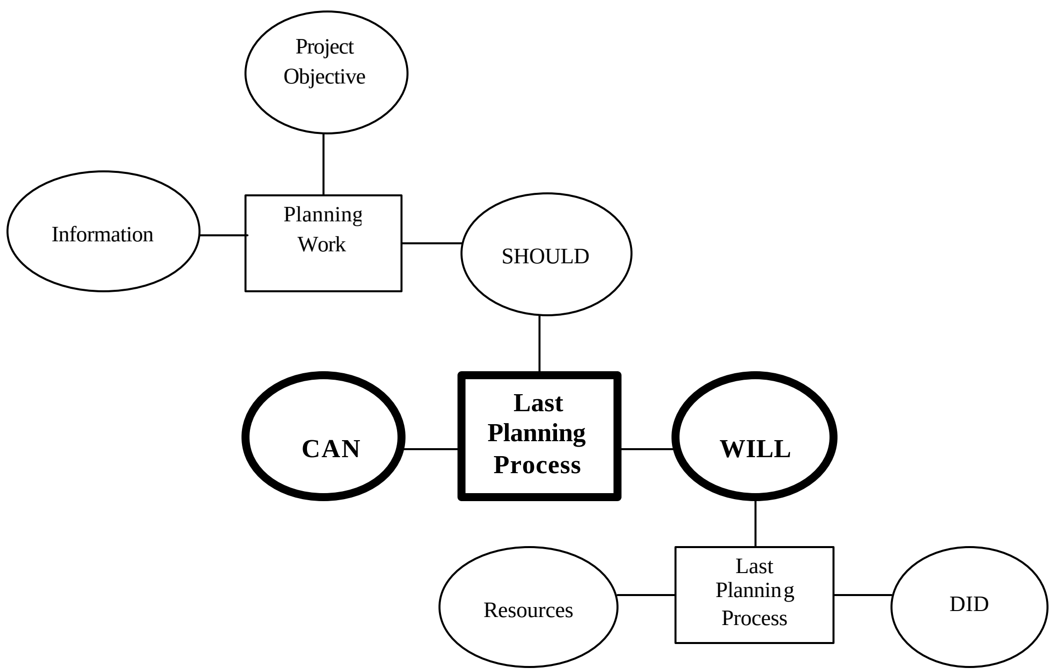

Figure 2.8. Last Planner System (Ballard and Howell, 1997)

A reliable assignment, one that gets done at the required time, determines what "WILL" be done, after considering both what "SHOULD" from higher-level schedules and what "CAN" be done based on the situation at hand. Assignments are likely to get done when they are well defined, resource sound, in the right sequence, and within the capacity of the crew. The Last Planner's job is to make certain the task in the assignment meets these criteria, and to reject assignments that do not. Last Planners can reasonably commit to completing the tasks on weekly work plans that meet these criteria.

To be effective, production management systems must tell what should be done, what can be done, and what will be done; then, they compare what was done to improve planning (Ballard and Howell, 1997). The term "SHOULD" is considered as "Hopefully", "CAN" means "Probably", and "WILL" means "Absolutely." Figure 2.9 illustrates the possible relationships among "SHOULD", "CAN" and "WILL".

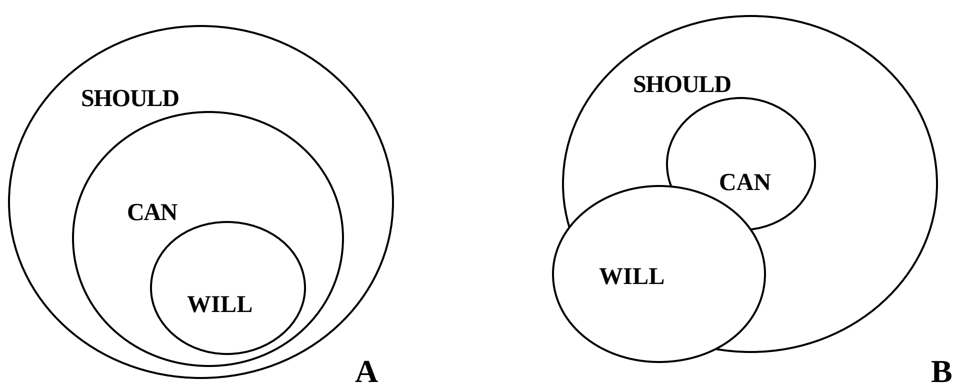

Figure 2.9. Diagram of "Should-Can-Will" (Ballard and Howell, 1997)

Diagram A in Figure 2.9 presents a scenario with the highest probability of task completion, and diagram B shows the certainty of failure. Referring to Figure 2.8, a reliable assignment determines what “WILL” be done, after considering what “SHOULD” and “CAN” get done based on the situation at hand. The assignments in diagram A are well-defined, sound, in the right sequence, and doable by the crews. Thus, the task is likely to get done at the required time. In contrast, the assignments in diagram B are out of plan and have much variability to be controlled. Thus, the probability of task completion decreases.

Table 2.2 provides a comparison of the differences between CPM and Last Planner, identified by the BOLDT Company, one member company of the LCI. BOLDT defined CPM as Strategic Planning and Last Planner as Production Planning. Table 2.2 shows the applicable concepts related to the results attainable from Figure 2.2 to Figure 2.3.

Table 2.2. Separate Strategic Planning from Production Planning (3rd Annual Lean Congress, the BOLDT Company)

CPM	Last Planner
• CPM logic embedded in software • High maintenance • Managing critical path • Focus on managing work dates • Planning based on contracts	• Applied common sense • Low maintenance • Managing variability • Focus on managing work flow • Planning based on interdependencies

Hal Macomber in Good2Great Associates describes project coordination and control in the Last Planner System:

> Project coordination and control in the Last Planner System is principally the practice of eliciting reliable promises and declarations of completion of those activities that release work to others. This allows the project work to stay in the desired sequence and advance as quickly as possible.

The LCI provided a recommendation for production control, and it described the brief key steps to follow the process of the Last Planner System as shown in Figure 2.10. The recommendations for the Last Planner System are as follows:

- Limit master schedules to milestones and long lead items.
- Produce phase schedules with the team that will do the work, using a backward pass, and making float explicit. – Stable schedules
- Drop activities form the phase schedule into a six-week lookahead, screen for constraints, and advance only if constraints can be removed in time.
- Try to make only quality assignments. Allow assignments to be rejected.
- Track PPC and act on reasons for plan failure.

2.4.1.5 FOUR LEVELS OF LAST PLANNER SYSTEM

The Last Planner has four levels in the Last Planner System (LPS): Master Pulling Schedule, Phase Schedule, Lookahead Plan and Weekly Work Plan (WWP). Figure 2.10 describes the detailed processes of the LPS.

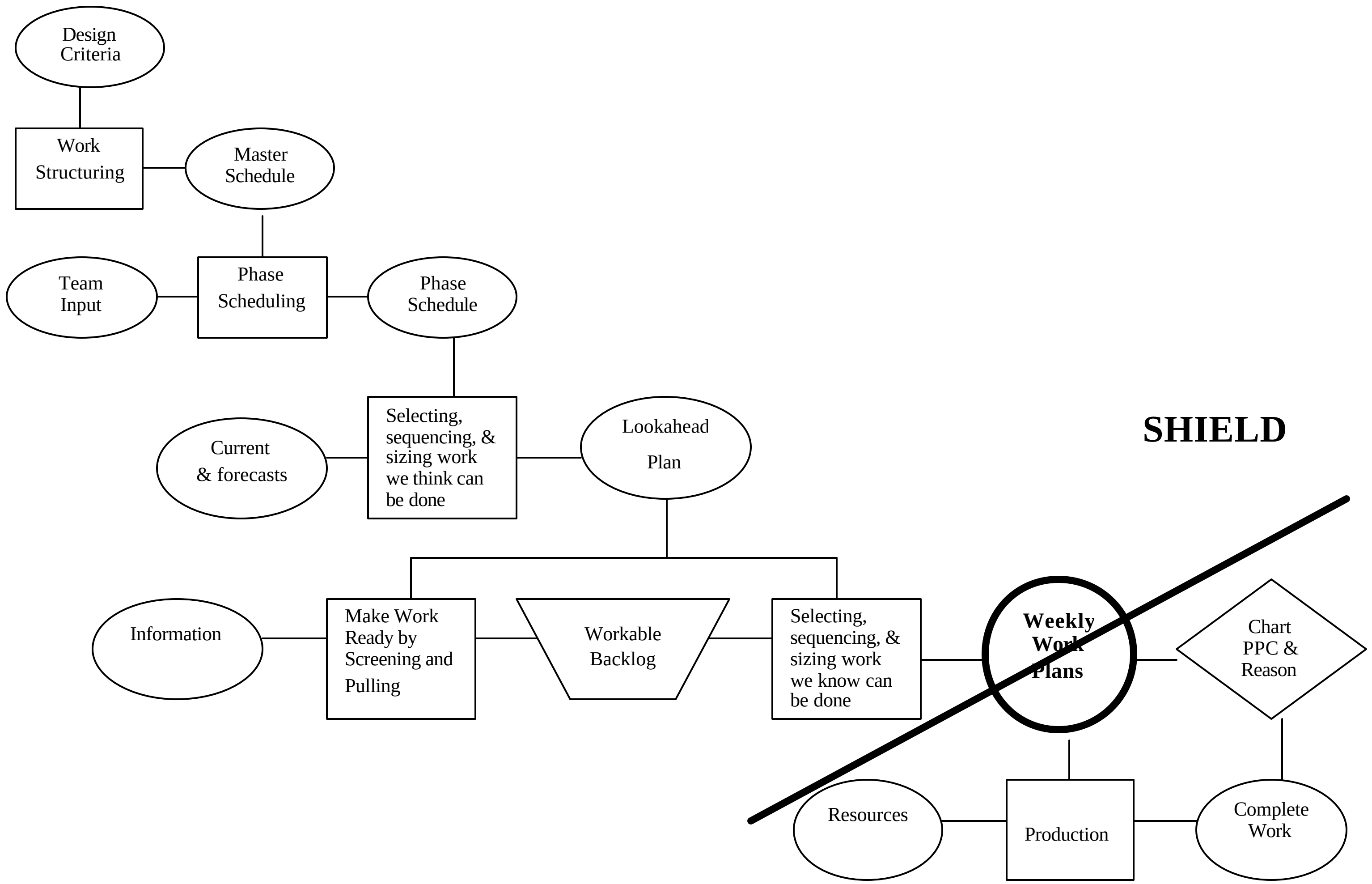

Figure 2.10. Process of Last Planner System (Howell, 2000)

2.4.1.5.1 Master Pulling Schedule

The master pulling schedule is the overall project schedule. The master pulling schedule is developed from design criteria that support the client's project objectives, and is determined by breaking the project into pieces and establishing their sequential relationships. The master pulling schedule has the level of detail to key milestones and develops phase schedules as the milestones approach. Milestone dates are determined by using the "pull" process from successor milestones, beginning with the project completion date and working backwards to the beginning of the project. The master schedule is initially constructed using the process mapping technique of Business Process Management known in Total Quality Management (TQM). Members selected to develop the master schedules organize the work flow based on their experience and common sense, focusing project objectives and requirements from owners, and then, constructing the process map on a large wall board using memo papers or post-it notes. The process mapping technique is highly recommended by the LCI to develop the master schedule. The master schedule establishes working structure and improves its effectiveness and efficiency.

The purpose of Master Schedules is to demonstrate the feasibility of completing the work within the available time, to develop and display execution strategies, to determine when long lead items will be needed, and to identify milestones important to client or stakeholders. (Howell, 2000)

The master schedule does not design the way work will be done to complete the work. It identifies activities, but does not portray the flow of requirements within and between tasks or activities beyond simple sequential relationships. Phase schedules are prepared by the team that manages the work in the phase. Master schedules can be understood as a sort of exploded assembly drawing of the project showing how the big pieces come together over time.

The master schedule cannot be used as the tool for managing activities before being developed in the phase schedule to support completion of master schedule milestones. Even though it should not be used as the tool directly to manage activities, its preparation early in the project is critical for understanding the project definition.

2.4.1.5.2 Phase Schedule

The Phase Schedule is prepared by the team in the phase and is prepared in finer detail than the master schedule. It must be prepared at least six weeks prior to the first activity. It also displays the way work will be done to complete the work within each piece or to coordinate the details of assembly. The purpose of Phase Scheduling is to produce the best possible plan by involving all those with relevant expertise and by planning near action to assure that everyone in a phase understands and supports the plan by developing the schedule as a team, to assure the selection of value adding tasks that release other work by working backwards from the target completion date to produce a pull schedule, to determine the amount of time available for contingency, and to decide as a group how to spend it. (Howell, 2000)

2.4.1.5.3 Lookahead Planning

The Lookahead Plan puts the workflow into the best achievable sequence and rate and matches labor and related resources to the work flow. It provides the workable backlog of assignments for each frontline supervisor and crew, screened for constraints. Operations are planned jointly by multiple trades and work that is highly interdependent is grouped together, so the work method can be planned for the whole operation. The Lookahead Planning has four major purposes. The first is to shape work flow in the best achievable sequence and rate for achieving project objectives. The second is to match labor and related resources to work flow. The third is producing and maintaining a backlog of assignments for each front line supervisor and crew, screened for design, materials, and completion of prerequisite work at the CPM level. This is the most important role to achieve a successful project. The final purpose is to identify operations to be planned jointly by multiple trades (Ballard 1997). A sample form of the Lookahead schedule is shown in Appendix A.

2.4.1.5.4 Weekly Work Plan (WWP)

The Weekly Work Plan (WWP) identifies make ready actions, assesses their feasibility prior to making assignments, identifies the best use of the crew or team's capacity, and acknowledges individuals' differences in light of the scheduled loads. The assignments for people who do work are made based on the quality criteria: definition, soundness, sequence, size and learning. Definition means work is ready to start. Soundness is resource readiness such as tools, laborers, materials, and information for the work ready. Sequence means the work is well sequenced according to the work orders. Size indicates the work is suitable for the capacity of work force. Finally, learning is for continuous improvement and adjustment. Figure 2.11 illustrates the typical Weekly Planning Cycle.

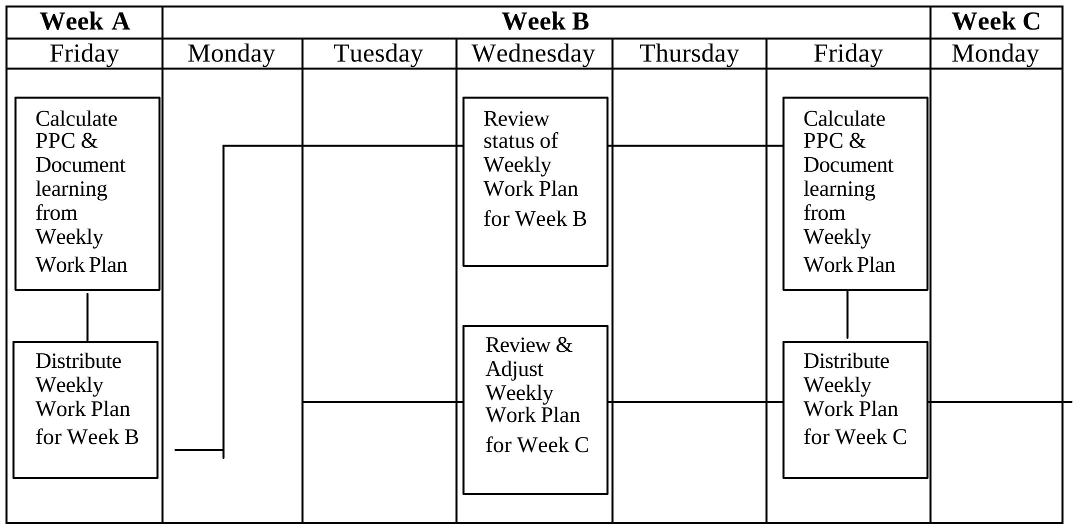

Figure 2.11. Weekly Planning Cycle

It recommends project participants meet twice per week. The first meeting is to calculate PPC and document learning from the week into the WWP, and to distribute the WWP for the next week. The other is to review the status of the week's WWP, and to review and adjust the WWP for the next week. A sample form of the WWP is attached in Appendix A.

Work planning meetings played a vital role in lean construction management practice, by facilitating the clear communication of commitments made by all trade contractors participating on the project.

The benefits of these work planning meetings are less time spent looking for work ready to be performed; a predictable flow of work by matching available labor to work flow; higher throughput of work; and greater ability to identify opportunities to improve work methods. By assigning work that can be done, as opposed to work that should be done, weekly work planning meetings contribute greatly to a project's success.

Percent Plan Complete (PPC) is indicated by the number of actual tasks completed divided by the total number of tasks assigned for a given week. It helps trace reasons back to root causes and reduce the cycle time for measurement. It is easy to understand and measure and provides consistent analysis and action on reasons for failure. Figure 2.12 presents a sample PPC. When the Daily Plan is executed, and an analysis of the report of the previous week is made, the PPC is calculated by dividing the quantity of work effectively executed by the total quantity of work that had been forecasted. A note explains the reasons for any work that had been forecasted but was not executed. When the PPC is calculated, a re-programming of services is made, indicating services that were executed and those that had been forecasted but were not executed. The immediate result of this re-programming is the calculation of a new date for finishing the construction (Junior, Scola & Conte, 1998).

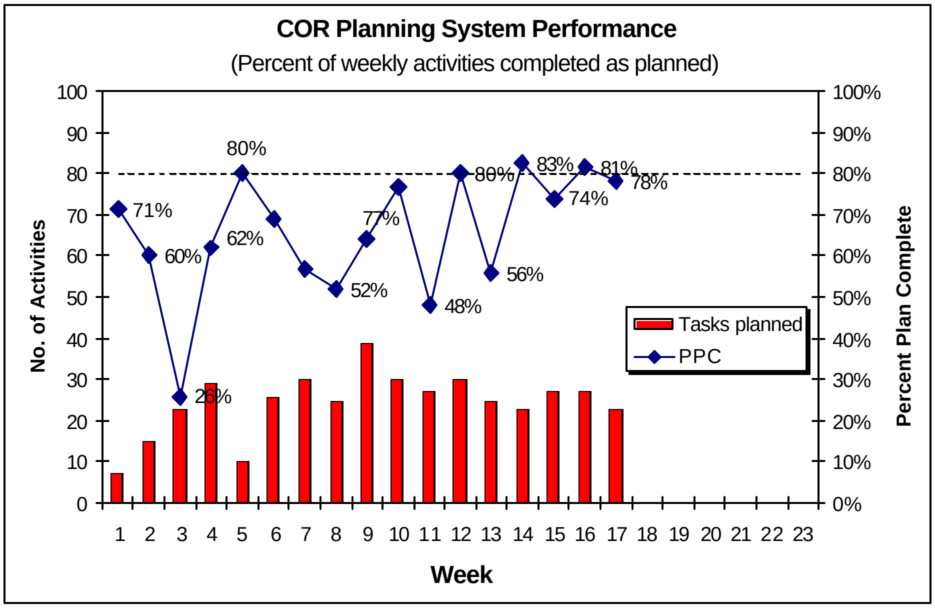

Figure 2.12. Percent Plan Complete

Shielding is introduced in the part of stabilization of work flow. It is an essential step in production control. The planning system needs additional levels in order to better manage uncertainty and complexity. The first level of Last Planner commitment is the implementation of shields to protect the direct work force from upstream variation and uncertainty (Figure 2.10). The shielding occurs in part simply from selecting only assignments that can be successfully completed, i.e., assignments for which all materials are on hand and all prerequisite works are complete. Figure 2.10 also presents the quality characteristics of Weekly Work Plans: selection of the right sequence and of the right amount of work that can be done. Shielding promotes accountability, improves control, reduces system facilitation problems, decreases non-production time and reduces burdens on front line supervisors.

2.4.2 Work Structuring

Lean Work Structuring is Process Design. As in project design, options must be considered and may reveal different dimensions of a problem. Work structuring expects iteration between consideration of the design of "What" is to be built, and "How" to build it. Since work structuring recurs, early decisions as to "What" must fully consider "How" or leave adequate room for later decisions. "Change" often is the result of over-specifying "What" while not considering "How" (www.leanconstruction.org). Lean Work Structuring (LWS) is different from the "Work Breakdown Structure" because the objective of LWS is to assure the best approximation of the lean ideal instead of defining each component. The actions for lean work structuring (LCI Seminar, 2002) are as follows:

- In what chunks will work be assigned to specialists?
- How will work chunks be sequenced?
- How will work be released from one production unit to the next?
- Will consecutive production units execute work in a continuous flow process or will their work be de-coupled?
- Where will de-coupling buffers be needed and how should they be sized?
- How will tolerances be managed?
- When will different chunks of work be done?

Products of work structuring are project global sequencing, organizational structure, supply chain configurations, master and phase schedules, operation designs, and detailed operation designs. Supply chain configurations include how the project hooks to external production systems. Examples of operation designs would be instructions on how to form-rebar-pour basement walls, how to use a tower crane versus rolling stock, or how to decide to cast-in-place versus precast.

2.4.2.1 AIRPLANE GAME

The "Airplane Game" is highly recommended by the LCI to make the concept of work structuring easy to understand and to show participants how to improve the production system design. The game consists of five workstations: workstations one through four are assembly lines and workstation five checks quality problems. There are four phases and each phase has its own logistics and company policy for the team members to follow. The first phase, logistics, is as follows: 1) Separate workstations in a non-linear configuration. 2) Workstations two through five have an incoming queue space. 3) Obstacles are placed in the production flow. 4) Aircraft are assembled in batches of five. 5) Batches must remain together through the final inspection. 6) Workers deliver each completed batch to the next workstation. 7) Raw material is placed as far as possible from the workstations. 8) Each worker must procure their own raw materials. The company policy for phase one is as follows: 1) Workers must perform only their assigned jobs and do not think at all. 2) Raw materials must be in supply containers. (No stacking) 3) Quality control (QC) problems are detected only by the inspector.

The second phase has the same logistics except that: 1) Separate workstations are in a logical production sequence. 2) There are no obstacles in the production flow. 3) Raw material is located at the appropriate workstation. The differences in company policy of phase two are as follows: 1) Workers can fix their own QC problems but not QC problems generated by another workstation. 2) QC problems can be verbalized by the inspector to the workers.

In the phase three, most of the logistics in phase I and II are changed to new logistics. The major differences are 1) Workstations are in a cellular layout. 2) Workers can have only one assembly at their workstation and are in the queue between workstations. 3) Aircraft are assembled in batches of one. 4) Components cannot be passed until its queue is empty. At this phase the company policy allows the workers some thinking, and workers can fix their own QC problems and verbalize these problems.

Finally, phase four has changes in assembly tasks to reduce the process duration at bottleneck(s) and provides balance flows. Other logistics and company policies are the same as those of the phase III except for two differences in company policy: 1) Workers can perform any step in the production process. 2) QC problems can be detected and repaired by any worker at each workstation. Through these production methodologies, the throughputs (aircrafts) are impressively increased with less waste and less QC problems. The workers are multi-skilled and self-managed. Consequently, all teams can obtain high productivity improvement.

Each team member plays the Airplane Game and adapts the following lessons (LCI Seminar, 2002): 1) Reduce variability, and then match buffer type, location, and size to the variability each is designed to buffer 2) Reduce setup times, and then reduce batch sizes that previously had been too costly to reduce 3) Reduce process durations at the bottleneck(s), thereby increasing throughput 4) Reduce non-bottleneck durations, which further decreases cycle time 5) Distribute the streamlined processes across workstations so each has approximately the same processing duration, and then restructure buffers accordingly 6) Develop multi-skilled workers who can achieve balanced flow by swinging between adjacent workstations to compensate for inability to match average processing durations and for variability around those averages.

2.4.2.2 WORK STRUCTURING AND OPERATIONS

Master Schedule and Phase Schedules, Global Sequencing, Project Organizational/Contractual Structure, and Supply Chain Configurations are all products of Lean Work Structuring. Figure 2.13 graphically shows Work Structuring and Operations. As can be seen in Figure 2.13, there are two phases: work structuring and design activities, and last planner. During first phase, the products of work structuring mentioned before are set up, and then the Last Planner decides which will go first for assignments to work. A 'First Run Study[3]' is performed at a project site to review whether the plan is effectively and efficiently constructed. The 'First Run Study' is the trial execution of a process or an operation in order to determine the best means, methods, sequencing, etc. to perform it. It is done a few weeks ahead of the scheduled execution of the process (www.leanconstruction.org: lean construction glossary).

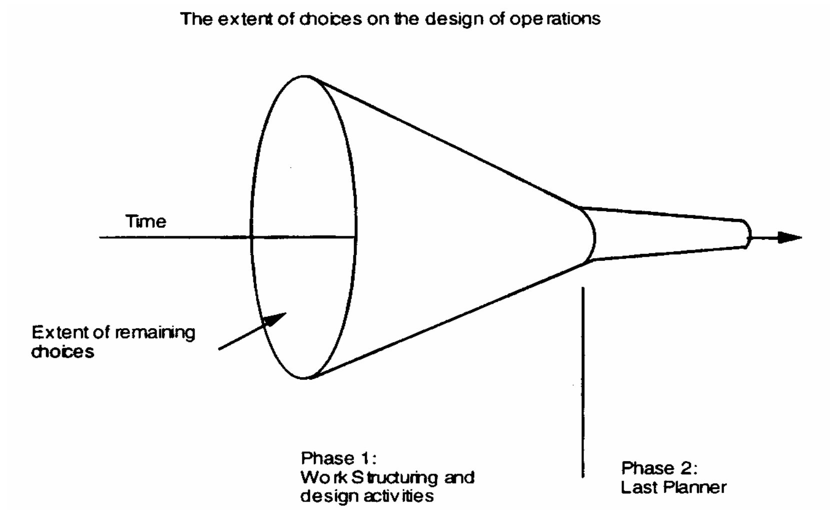

Figure 2.13. Work Structuring and Operations (LCI Seminar, 2002)

2.4.3 Production System

The Lean Construction Institute identified project problems in production management terms. It also provided metrics and goals of production system design, and suggested the guidelines for self-management as well.

- Activity/Contract mentality ignores the physics of production.
- Disregard of variability: Fails to provide a basis for coordination.
- Processes not in control.
- Lack production knowledge; e.g., workflow reliability, lead times, defect rates, process and operations design etc.
- Little learning; repetitive failures.
- Extreme fragmentation, even inside companies.
- Central control fantasy; 'push' system ignores the process of making and keeping commitments.

Production System Design has key metrics for throughput [4], cycle time, work-in-process [5], and takt [6] Time. The key metrics follow:

- Throughput (TH): production rate determined by the processing duration at the bottleneck(s).
- Cycle Time (CT): time required for a single unit of product to transit the system = sum of processing durations + sum of queue times.
- Work-in-Process (WIP): the number of partially completed units of product in the system.
- Takt Time: that production rate (TH) which matches the demand rate for the product.
- [Note: TH = WIP / CT]

The goals for Production System Design are to increase the throughput rate (TH) to match the demand rate. This is takt time, and it minimizes cycle time, reduces work-in-process to the level needed to maintain throughput, and minimizes resources required.

The LCI provides the guidelines for moving towards self-managing production cells. They follow the sequence, inspect one's own work, do not get more than one step ahead of the customer, help others maintain work flow, and make suggestions to improve safety, product quality, productivity, or quality of work life.

2.5 HUMAN RESOURCE MANAGEMENT

How to manage people at work successfully has been a major question since industrialization. Greater emphasis is now being placed on maintaining a smaller but highly motivated and highly productive workforce. As such, human resource management (HRM) has come to occupy a more prominent role in the employment relationship. HRM is a term that is now widely used but loosely defined. Beer et al. (1985) in "Readings in HRM" states that "human resource management involves all management decisions and actions that affect the relationship between the organization and employees – its human resources." Most researchers who believe that HRM is an approach to manage people effectively agree that people are the key factor; valued assets in which to invest and sustainable competitive edge can be achieved through them. Organizations can use HRM to gain competitive advantage because it is difficult for competitors to duplicate (Sparrow 1994). That is, while technology and capital can be acquired by almost everyone at any time, for a price, it is rather difficult to acquire a ready pool of highly qualified and highly motivated employees. This brings researchers to the HRM philosophy, which regards people as the most valuable assets. In other words, it is the human resource among all the factors of production that really makes the difference.

2.6 SUMMARY

The Lean Construction Institute (LCI), in 1997, approached lean construction with the viewpoint of developing "the foundation of a new form of project management in its control, performance, project delivery and coordinating action". However, most do not believe this approach. They often implement some of the ideas from lean to improve their current practice of the traditional methods, i.e., focusing on more detailed planning. Moreover, they are reluctant to change current planning and control systems such as CPM and Earned Value, even though these cannot achieve lean goals and contradict lean ideas. With these attitudes toward lean construction, implementing lean principles may cause lean users more confusion and frustration. Therefore, it is necessary to examine whether project participants properly understand and apply lean principles and concepts to real construction projects. It is also essential to identify the project participants' attitudes toward the current lean construction and to discover the types of barriers that may exist in the current work environment.

In addition, several researchers have strongly regarded lean construction as one-sided by insisting on the lack of consideration for HRM. One such prominent researcher, Stuart Green, a professor at the University of Reading in the UK, argues that lean construction strengthens only "the limited domain of instrumental rationality and technical efficiency," and "the basic concepts of HRM seem to be strangely ignored by those who advocate lean production"(Green, 1999). Even though Howell and Ballard, co-founders of the Lean Construction Institute (LCI), in their paper "Bringing Light to the Dark Side of Lean Construction: A Response to Stuart Green" (Howell and Ballard, 1999), have tried to put Green's argument into proper perspective, there is unfortunately little empirical research data to refute or verify this argument. Thus, this study also assesses the participants' job satisfaction, especially subcontractors' job satisfaction, related to the lean construction.

Chapter 3: Research Methodology

Two major elements are involved in developing a procedure to assess lean implementation – understanding the relationship between lean production systems and other related factors, and determining how to measure and evaluate them. This chapter describes the methodology to develop the foundation for this procedure.

3.1 RESEARCH MODEL

A research model is developed to understand the relationship between lean planning systems and other factors such as organization, attitudes, and contracts. Seymour (1999) suggested a conceptual link between systems and organization. Howell, a co-founder of the LCI, agreed that these two factors exerted various influences on lean implementation and added two more factors, attitudes and contracts, at a meeting held at The University of Texas at Austin on January 15, 2002.

This research will focus on four major elements in organizational factors – organizational support, training (knowledge), coordination, and communication between the owner and general contractor, owner and subcontractors, and the general contractor and subcontractors.

Project participants' attitudes toward lean construction are also critically sensitive factors for successful lean implementation. Many studies indicate that human resources have a major influence on lean implementation and its success. Coffey (1999), in 'Developing and Maintaining Employee Commitment and Involvement in Lean Construction', states that "implementation of lean construction is in its infant stage, so that lean construction yet depends upon the potential and abilities of employees in order to successfully perform many of its functions and achieve its potential." The report indicated that "somewhat in order of 70% of improvement originated from the individuals who carry out the work." Several elements are involved in project participants' attitudes – involvement that is founded upon the employee's ability to participate in decision-making concerning their own work, commitment that drives from genuine involvement, motivation, enthusiasm to employ lean and carry out successful implementation, open-mindedness and having a positive vision to accept changes for lean construction.

Contractual factors have to be initially oriented to create strong involvement of the owner, general contractor and subcontractors, and to define roles and responsibilities of project participants. Ballard and Miles (1997) indicated "contracts are one dimension of organizational relationships", and "cooperation must be based upon realistic appreciation and recognition of the self-interests of the participants in a project. The contracts must support these self-interests and provide a framework for the overall best success of the project." Contracts can create better coordination and help keep a promise among project participants, and should support effective implementation of lean systems.

This study began with the assumption that if the four factors of lean planning systems, organization, attitudes, and contracts were mutually and effectively combined, lean construction could be successfully implemented. Figure 3.1 illustrates the relationship between the lean planning system and the other three factors.

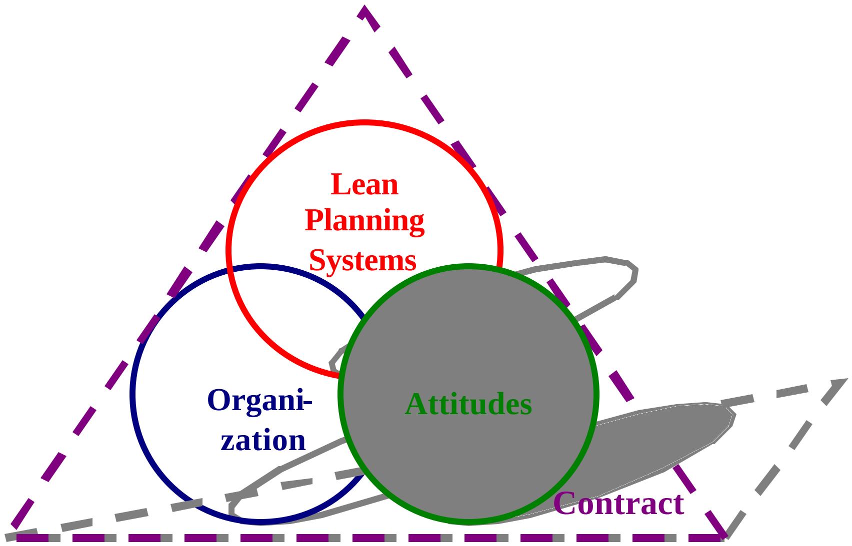

Figure 3.1. Relationship for Successful Lean Implementation

3.2 RESEARCH PROCEDURE DEVELOPMENT

In this study, data was gathered through a combination of a short written questionnaire survey and interviews. It is well-known that human factors have an important influence on implementing lean systems, so case studies were limited to active lean construction projects and data were gathered through interviews with project teams and workforces in action. Collecting data from a broad spectrum of project participants enhanced the opportunity to assess with some accuracy the implementation and effectiveness of lean approaches. Figure 3.2 illustrates the research procedure. The first step was to take the literature review and develop questions for the interview and simple questionnaire. At the same time, lean member companies were contacted to obtain possible lean project sites for case studies. After arranging case studies, the next step was to visit the sites and conduct interviews with the project teams. Team participants included the general contractor and subcontractors. The final steps were to summarize and analyze findings, and then to derive conclusions and present recommendations.

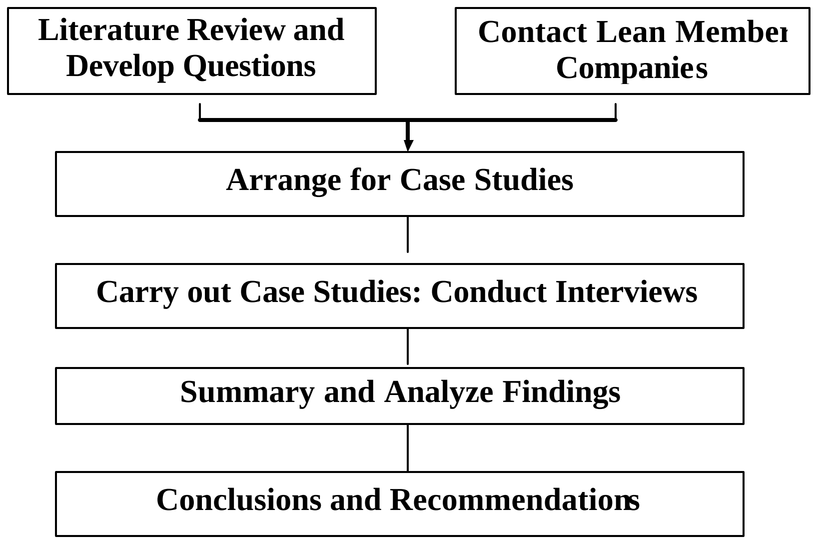

Figure 3.2. Research Procedure

3.3 ANTICIPATED FINDINGS FROM CASE STUDIES

This study is anticipated to show through the case studies: "to what extent is lean construction adapted in the current construction industry?" To verify this subject, this study will focus on finding the following from the case studies:

1. How effectively is lean construction applied to current construction projects?
    a. Which lean principles and tools are applied in current construction fields?

b. How properly are the lean principles and tools implemented?
c. What effects does lean construction have on current construction projects?

2. What is the climate of the organization currently employing lean construction?
   a. What are the attitudes of the general contractor and subcontractors toward lean construction?
   b. Is the general contractor and subcontractors ready to accept lean construction?
      i. Management efforts or influence on lean awareness
      ii. Participative management or employee involvement
      iii. Contribution toward lean implementation
   c. How much is the general contractor and subcontractors aware of lean principles and concepts?
   d. What effects does lean construction have on project participants?
3. What are the benefits and barriers of lean implementation?
   a. Which benefits can be identified by lean implementation?
   b. Which barriers can be identified by lean implementation?
   c. What are the opportunities for improvement of lean implementation?

3.4 QUESTIONNAIRE SURVEY

Questionnaires administered in addition to interviews can provide valuable insight into the effectiveness of lean ideas on a construction project. The questionnaire had two parts, one for the general contractors and the other for the subcontractors. The questionnaire had only one page for each level of the workforce surveyed, and was based on evaluation formats made by one of the lean member companies. This questionnaire provided quantitative results for reference, but was not used to assess the level of lean construction. The primary focus of the questionnaire was to assess the attitudes and comprehension of the project participants toward lean construction.

3.4.1 General Contractor's Evaluation

All questions were developed on a scale of 1 to 5. One represented 'much less' or 'much worse', and 5 represented 'much more' or 'much better'. Three represented the average.

- Managerial Time & Attention: Compared to other similar projects not employing lean construction, how was the managerial time and attention consumed on this project?
- Job Satisfaction: Compared to other similar projects not employing lean construction, what was the level of job satisfaction on this project?
- Turnover & Absenteeism: Compared to other similar projects not employing lean construction, how was the turnover and absenteeism on this project?
- Competitiveness: Do you think the company that employs lean construction is more competitive in the construction market compared to companies not employing lean construction?

3.4.2 Subcontractors' Evaluation

All questions were on a 1 to 5 scale. One represented ' much worse' or 'much less', and 5 represented 'much better' or 'much more'. Three represented the average.

- Planning & Coordination: Compared to other similar projects not employing lean construction, how was the planning and coordination on this project?
- Involvement & Commitment: Compared to other similar projects not employing lean construction, how was the involvement and commitment of subcontractors on this project?
- Fire-fighting: Compared to other similar projects not employing lean construction, how many unexpected and urgent problems have been experienced on this lean project?
- Productivity: Compared to other similar projects not employing lean construction, how was the productivity on this project?
- Unplanned Overtime (OT): Compared to other similar projects not employing lean construction, how was the unplanned OT on this project?
- Job Satisfaction: Compared to other similar projects not employing lean construction, what was the level of job satisfaction on this project?

The questions were revised for conducting the interviews. The next five questions were added for the subcontractors' evaluation.

- Rework: Compared to other similar projects not employing lean construction, how was the rework due to common problems (design changes, priority order and prerequisite work) on this project?

- Resources Availability: Compared to other similar projects not employing lean construction; assess the resources availability (materials, tools, equipments and information) on this project?
- Working Conditions: Compared to other similar projects not employing lean construction; assess the working conditions (over-crowed work area, crew interference and stacking of trades) on this project?
- Wasted Time: Compared to other similar projects not employing lean construction; assess the wasted time (waiting and idle time) on this project?
- Work Assignments: Compared to other similar projects not employing lean construction; assess the work assignments (definition, size, sequence and soundness) on this project?

3.5 FACE-TO-FACE INTERVIEWS

Interviews were structured to gather information from the selected range of project personnel in order to accurately assess the effectiveness of the lean systems evaluated. At the project site, interviews were conducted with the project manager, superintendent, project and field engineers, and superintendents or foremen of subcontractors. Those interviews were structured to determine how lean construction was actually implemented in the field, and to assess its strengths, weaknesses, and overall effectiveness from a field point of view. The interviews were conducted individually at convenient times for the participants. It took 30 minutes per participant. The interviews focused on the above questionnaire and the following additional questions to provide a general framework for interviews conducted in the field:

- Have you had any training related to lean construction?
- Do you have any experience with lean construction?
- What do you think about lean construction?
- What is the major difference in lean construction compared to traditional construction?
- What are the benefits and barriers in implementing lean construction?
- What are the opportunities for improvement in lean construction?
- Do you have any comments related to lean construction?

Through face-to-face interviews, more broad and detailed data were anticipated to be collected. The interviewees could directly describe their own experiences, any situations that had happened to them, and their own attitudes toward lean construction. The face-to-face interviews provided real-world experiences on lean implementation.

Chapter 4: Project Case Studies

Seven in-depth case studies were carried out for this research using the procedure developed in Chapter 3. Three additional projects were briefly summarized by project managers during the process of investigating one of the seven projects. The study included three projects in Texas, two in California, one in Wisconsin, and one in Michigan. The projects included a new pharmaceutical company office building, an office renovation, a new hospital community center, a hospital renovation, a college of medicine building, a new university dental school, and a university chemistry hall renovation.

One site visit per project was made during the construction period. Most project managers did not want the interviews to interrupt working schedules, so interviews were carried out with the staff of the general contractor (GC) and key subcontractors. The interviews focused on the questions developed in Chapter 3. At first the goals of this study were to interview project team members including project manager (PM), superintendent, office engineers, and field engineers according to their time availability, and then, to interview each key subcontractor one by one to hear their personal thoughts without the influence of the general contractor.

Ballard and Howell (1994) in their paper "Implementing Lean Construction: Improving Downstream performance", emphasized that planning must be extended downward to foremen, sub-crews and individual craftsman until work has been executed. Thus, the case study scope initially included craft workers, but it was found that they were not aware of any new work system or method, and merely followed the foremen or superintendents' directions. As a result, the study rearranged the scope of interviewees to the foremen level or the superintendents of the subcontractors. Typically the Weekly Work Planning (PPC) was held on Tuesday or Thursday, so most visiting dates were scheduled on one of those days to attend the meeting. The researcher wanted to observe how the meeting was managed, by whom and under what criteria, how long it took, and how much the subcontractors were interested in the meeting. As mentioned in Chapter 3, the case study was focused on the mutual relationship among the lean production systems, namely organization, attitude and contract. Projects hired a mixture of union and non-union trades with the exception of one project.

Among the case studies, case study A had been already completed and had the best reputation for its successful lean implementation. The project fully implemented all aspects of lean construction: planning systems, concepts and principles, thus, case study A deserved to be a benchmark project for comparison to the other case studies. Case study A will be discussed in section 4.1.

Table 4.1(a) and 4.1(b) summarizes the interviewees and provides a brief project description of the budget, schedule, contract, and lean systems employed in the project at the time of the site visit. The abbreviations shown in Table 4.1(a) and 4.1(b) are as follows:

Mos. – Months, GMP – Guaranteed Maximum Price, CPM – Critical Path Method, WWP – Weekly Work Plan, PPC – Percent Plan Complete, JIT – Just-In-Time delivery, Const. Planner – Construction Planner, GC – General Contractor, Subs – Subcontractors, PM – Project Manager, MEPE – Mechanical Engineering Project Engineer

Table 4.1(a). Project Descriptions (I)

	Project A – TX Renovation of Chemistry Building	**Project B- TX** Hospital & Support Buildings	**Project C – CA** Chemistry Lab & Offices	**Project D – CA** Office Renovation	**Project E – MI** Health Center
Budget (approx.)	$ 28.9M	$ 55M	$ 5.5M	$ 1.1M	$ 8M
Project Duration	12 mos.	18 mos.	6 mos.	8 ½ mos.	13 ½ mos.
Contract Form	Cost Plus Fixed Fee / GMP	Cost Plus Fixed Fee / GMP	Unknown	Lump Sum	Lump Sum
Lean Systems	• Master • Phase • Lookahead • WWP • PPC • Const. planner • JIT	• Master • w/ CPM • Phase • Lookahead • WWP • PPC • Const. Planner	• Lookahead • WWP • PPC	• Lookahead • WWP • PPC	• Master w/CPM • Lookahead • WWP • PPC • JIT
Interviewee	• GC: PM, Engineers • Subs: Plumbing, Mechanical, Fire Protection,	• GC: PM, Engineers • Subs: Electrical, Mechanical, Steel Erection	• GC: PM, Engineers • Subs: Sheet Metal, Mechanical, Electrical, Plumbing	• GC: PM, Engineer • Subs: Superintendent	• GC: PM, Engineer, Superintendent • Subs: Plumbing, Ceiling and Partition, Electrical

Table 4.1(b). Project Descriptions (II)

	Project F– TX Renovation of a Factory to a Health Center	Project G – WI University Dental School	Others		
			Project H-1	Project H-2	Project H-3
Budget (approx.)	Not yet determined	$ 20M	$ 3M	$ 17M	$ 125M
Project Duration	Not yet determined	18 mos.	10 mos.	14 mos.	40 mos.
Contract Form	Not yet contracted	Cost Plus Fixed Fee / GMP	Unknown	Unknown	Unknown
Lean Systems	• Master w/ CPM • WWP • PPC	• Master w/CPM • Phase • Lookahead • WWP • PPC	• Master • Look-ahead • WWP	• Phase • Look-ahead • WWP	• Master • Look-ahead • WWP • JIT
Interviewee	• GC: Engineers, MEP E, Superintendent • Subs: Mechanical, Electrical, Drywall	• GC: PM, Superintendent, Facilitators • Subs: Drywall and Insulation, Electrical	• GC: PM	• GC: PM	• GC: PM

4.1 CASE STUDY A

As mentioned before, when this case study project was studied, it had already been completed. The project had a good reputation for its successful lean implementation. It was difficult to find project participants as they had already been dispersed to other project sites. Project participants were individually contacted, and appointments were arranged to meet with them at their current job sites or offices. Most of them had a good impression of the project. For the interviews, the project manager, project engineer, and three subcontractors were identified.

4.1.1 Project Description

The project was a renovation of a university chemistry building originally built in 1925. It was made of load-bearing masonry with a concrete encased steel structure. Its dimensions were thirteen feet floor to floor with 84,000 square feet. The project budget was $28.9M and the actual construction cost was $22M. The construction contract was a negotiated, Cost Plus Fixed Fee/Guaranteed Maximum Price contract. The construction duration was 12 months. Approximately 90% of the work on this project was subcontracted. The project had contracts that required employing lean construction among the owner, the general contractor, and subcontractors. The project was actually over budget and behind schedule at the time of project completion; however, it was considered an unavoidable result by the owner because the project had been difficult, and the problems mostly stemmed from differing site conditions and numerous change orders from the design team and owner. The outcome of this project was considered to be equivalent to an outcome of saving a half a million dollars and reducing the duration by three months.

4.1.2 Results

Results were gathered from observations (the weekly planning meeting, PPC, root causes), interviews with project personnel, and collection and analysis of the short questionnaire survey. Results are described below and focus on the lean planning systems, organization, attitudes, and contract.

4.1.2.1 PROJECT PLANNING SYSTEMS AND PROCESS

This project was one of the projects that effectively and successfully employed the whole Last Planner systems and other lean principles.

- Weekly agenda
  1. Reviewed PPC from the last 2 weeks
  2. Calculate PPC for the prior week
  3. Construction Planner
  4. Six-week Lookahead
  5. Weekly planner with workable backlog
- Monday – Lean meeting
- Tuesday – Problem solving meeting
- Wednesday – Results meeting

The lean concepts used at the project were Just-In-Time deliveries (JIT), coordination of first in – last out, clean-up across trades, sequence of work scheduling, and work packages.

The general contractor initially performed the following in order to use lean tools during the project:

- Negotiated with subcontractors after the interview process
- Held two training sessions
- Developed the master pull schedule
- Eased into the six-week lookahead
- Facilitated the construction planner
- Brought in a weekly planner
- Developed PPC charting
- Developed tools to be used by the trades

The construction planner was used to shield plans from unreliability, provide information upstream to create reliability, identify constraints, and link the plans to the milestone pull schedule. The six-week lookahead schedule created reliable work flow. It was a communication tool for other trades, and was used to monitor work against the pull schedule. The weekly planner was used to identify where trades were working, resolve the final sequence of work, identify reliable work (constraints were removed), and identify the workable backlog. It was also a vehicle for calculating the PPC. The PPC was used to identify major problems and identify ways to improve planning performance.

4.1.2.2 ORGANIZATION

The project properly followed lean concepts and principles and used lean tools. The project manager encouraged all participants to participate in lean implementation. She managed the whole systems under the lean ideas. The subcontractors at first thought that the lean tools were nothing but more paper work. However, once they understood and used the tools, they realized those tools were actually useful and effective in helping them to manage their schedule and planning.

The project manager preferred the pull schedule rather than the CPM push schedule. Under the CPM, only one person has the responsibility to control the project and compel the participants to follow the plan. It is based only on that person's intuition and experience, and is derived from a personal schedule – the project schedule is not derived from the participants. It is not realistic. The lean pull schedule encourages all participants to be involved in the schedule, share their requirements, to coordinate and understand their situation, and to develop the most optimized schedule for all. This kind of progress strongly tied them together and improved team building.

The owner of this project initially wanted to employ lean construction for the project. Thus, the representatives of the owner found a construction company to implement lean construction and chose this general contractor after realizing it had a strong background in lean construction. The owner representatives were enthusiastic to implement lean construction. They attended lean planning meetings, problem solving meetings, and were involved in decision-making. They were supportive of the general contractor to implement lean construction.

In this project, the researcher found that the coordination and communication were highly developed among all project participants, including the owners.

4.1.2.3 ATTITUDES

The project atmosphere created camaraderie between the general contractor and subcontractors, and developed the spirit of teamwork and mutual respect under difficult site conditions of renovating an historic science building. The project had approximately 100,000 hours without a lost time injury and had minimal unanticipated rework. It improved the owner's commitment to the general contractor.

The project manager indicated that team spirit was developed, and all participants shared each other's information. They respected each other and shared their tools on site. The participants also honestly trusted one another. For instance, a worker in a trade damaged important materials of another trade that was stocked on the site. As soon as he realized the material damages, he went to the foreman who managed those materials and told him what he had done. The foreman was able to provide new materials before they were needed.

This project showed that to obtain successful lean construction implementation, there are requirements that lean users must consider. Those include keeping an open mind, pursuing education in lean principles at all levels, and facilitating the program.

The pull scheduling motivated the subcontractors. Participants could be involved in coordinating their schedules together through communication. One of subcontractor foremen could maintain his own schedule with a better relationship among other subcontractors.

There were opportunities for improvement at the project. More effort and adjustments to the master pull schedule were needed and improvement of reliability in deliveries was required. Commitment from the trades and subcontractors was identified as a major factor that needed improvement.

Overall, all project participants were well-motivated to implement lean construction. They were extremely positive on lean project principles, and respected the project manager's ability to implement lean. Interviewees indicated that they now missed the work environment of this project.

4.1.2.4 CONTRACTS

The project had contracts between the owner and general contractor, and the general contractor and subcontractors. The owner initially wanted to employ lean construction, and contracted with the general contractor to employ and implement lean construction. The general contractor negotiated with subcontractors after the interview process, then made contracts to require full implementation of lean construction.

Foremen of the subcontractors later claimed that if the contract did not exist, they would not have kept on implementing lean construction, when they at first did not understand its necessity and benefits.

4.1.3 Feedback from Interviews

4.1.3.1 GENERAL CONTRACTOR INTERVIEWS

The project manger indicated that the project was difficult to build. There was not enough information provided by the architectural engineer. More than 250 design changes occurred during the construction phase. Drawings were not provided on time.

The forms used on the site were difficult to use at first. The large number of forms to be filled out made the foremen think they just had more paper work. Some foremen had difficulty understanding how to use them. On this project, the project manager did not provide all the forms at once. The first time, she gave them a form of the last planner then, instructed them on how to use and be familiar with the form. Once they understood how to use it and what benefits the form had, she gave them another form. Soon, the subcontractors fully understood all forms that were to be used on the project. It was a more effective way to help participants understand how to use the forms and to plan their work. At first, the lean meeting took 1 ½ to 2 hours. Once the participants understood their duties, the length dramatically dropped to 30 minutes.

The project manager learned from this project that management needed to be more rigid in checking the planning and progress. Over the construction duration, new subcontractors joined the project. Because they did not know about lean construction, it was difficult getting involved in the lean culture. For them, the project site conducted the Airplane Game, introduced in Chapter 2, to help them understand the importance of coordination and communication. For several weeks new participants were not required to prepare any planning or scheduling. Only attendance at the meeting was required. At that time, participants had to understand how the meeting was running, what information must be prepared, and to be familiar with other participants. Later they understood what they had to do.

This project was the first job in which the project manager had used lean principles. She had work experience in architectural engineering, but this was her first construction field assignment as a project manager. The project was considered to be successful. The owner wanted to keep her to work on another project, so she was currently working on the other project assigned for the owner.

The project engineer believed that the project properly followed lean concepts and principles and used lean tools. The project had many problems. There was no active involvement of the designer. There were too many changes and not enough information. However, all participants were satisfied with this project even though it was difficult. They enjoyed the new challenges in lean construction.

The project engineer indicated that lean construction seemed to have many effective principles and concepts, but the last planner was the most effective one to be adapted to the construction industry. It looked like a good tool to improve performance by doing more detailed planning.

4.1.3.2 SUBCONTRACTORS INTERVIEWEES

The mechanical foreman took two official seminars prior to the start of this project. He indicated that this project was a good one. Participants built the schedule together, shared tools together (job tool boxes), and had respect for each other. There was a good relationship among all participants.

The six-week planning helped to remind him to order material for delivery to support the schedule. The construction planner also made it easy for him to obtain information and feedback on work that was ready to install. However, he thought that two-week planning was more effective than one-week planning because one week did not provide enough time and details for effective feedback.

Just-In-Time (JIT) delivery saved the mechanical foreman material costs. The foreman imported his glass pipes from Europe. He had experienced material damage at a previous project, which had a smaller sized project site than this project. At first when he was assigned to this project, he stocked the materials on site and material was damaged. According to the project manager's request, he tried to apply JIT delivery. When it proved successful, he felt positive about the concept. He used two pick-up trucks for delivery. However, he still preferred to have a stock yard if the site could provide enough safe space because the materials were sensitive and needed a long delivery time from overseas. He could not be 100% sure of the delivery promise from suppliers.

The project, at the beginning, required an unrealistic schedule from the subcontractors. That was the greatest challenge of the project. For instance, when the mechanical foreman made the draft master pull schedule, he had no information from the designer and had to develop the schedule based on intuition and experience. Sufficient information and involvement of the designer is absolutely required for successful lean construction.

Through last planning, he could obtain a stable labor level. He knew what he needed to do, what others wanted him to do, and what he needed from others. Everybody knew each others' work tasks. Last planning also made it easy to figure out who was at fault for any delay.

The first time the mechanical foreman attended the planning meeting, he encountered too many planning forms. This really frustrated him. However, the project manager had provided forms one by one to help the subcontractors understand how to use each form. The forms were computer-based. The mechanical foreman did not have his own computer on site. From this project, his company realized that foremen needed their own computers. Soon he had his own computer at the site.

The mechanical foreman thought that lean construction was beneficial to his work. He was motivated by lean construction. He was proud because he knew about lean construction and he had full responsibility for the planning and scheduling of mechanical work. He felt self-fulfillment, recognition by others, and achievement. His company and he were assigned to a new project employing lean construction by the general contractor.

The fire protection foreman claimed that the major benefit of lean construction was the relationship with the owner. The participants knew what the owner wanted to obtain. Through the meetings, all participants even the bottom level management could understand the owner's objectives. For example, the subcontractor knew even why the owner preferred gray carpet. Usually the general contractors put up "blinds." They let the subcontractors know only what they wanted to let them know. However, the lean construction principle removes the "blinds." Lean improves the connections amongst the owner, general contractor and subcontractors.

Lean construction helped in project review. The owner, general contractor and subcontractors were involved in the meeting and reviewed problems. There was face-to-face problem solving, so that all participants knew the limitations of the project. Coordination with others was greatly improved.

The fire protection foreman's boss wanted to keep the lean performance. He thought there were two benefits. One benefit was the company could have better connection and communication with the owner and the other was that there was great improvement in team building. The subcontractor should not try to save money, but let the owner save money. This result would not provide a direct effect on the company, but the company would have a priority on getting future jobs from the owner because the owner would like the company that saved money for them.

On this project, the relationships between the general contractor and subcontractors worked properly, but the job itself required rework not related to "lean," but to design changes and differing site conditions.

There seemed to be too much time required at the beginning to prepare for the project. However, this was necessary to obtain good performance later. Sometimes no drawings from the designer to assist in scheduling were available, and the foreman had difficulty in preparing the planning according to the Last Planner.

Lean construction seemed to be an information-type tool. He did not know all about the lean principles, but thought the Last Planner itself was an effective tool for more detailed planning.

Whenever the subcontractors had problems and wanted to hold a meeting, the project manager held the meetings with the owner, engineers, architect (if possible) and key subcontractors. This allowed for effective decision-making and changes according to unanticipated situations.

The fire protection foreman liked lean construction. He thought it was a better production system. He preferred to join in the upcoming lean construction projects by the same general contractor of this project.

The subcontracting company at which the plumbing foreman was employed is a member company of the LCI and has a strong background in lean construction. The company has used lean principles for four years. It has applied the Last Planner to jobs regardless of other subcontractors or the general contractor. However, this project was the first experience in which all other subcontractors were executing lean principles.

The lean system forced the plumbing foreman to keep a complete checklist rather than work from memory. The checklist was a vital tool. The Last Planning was important to the crews and let the foreman show others what he needed to complete before their work was initiated. The subcontractors could check every resource at point ‘A’ to do the work to get to point ‘B’.

Lean construction gave the best opportunities to the participants to give the owners good quality construction work and to meet and beat the project schedules. To the lean users, lean construction provided opportunities to reduce the fluctuation of labor due to fewer problems while having fun during the work rather than being in conflict over work sequence.

The first time he got the planning forms, he did not want to use them. Once he understood the forms and what he needed to do, he had fun filling out the forms and prepare the work. Now he was going to be a superintendent at his company, so he trained his foremen by himself. All his foremen were now familiar with lean implementation. He showed the researcher the lookaheads, construction planners, and two-week scheduling of other projects in which he was involved.

He wanted to have a simple computer-based software program for the Last Planner planning. Excel sometimes caused wasted time in the process of finding the needed file, and opening, saving and closing the file. Also it was difficult to update and provide feedback. Just a simple software program would be a beneficial improvement to the current Excel system.

4.1.4 PPC and Root Causes of Failure

PPC was measured for a total of 49 weeks and had an average of 85%. The graph in Figure 4.1 indicates approximately half of the PPC of the project. According to the LCI, over 80% work complete is considered successful implementation (Pappas, 2000).

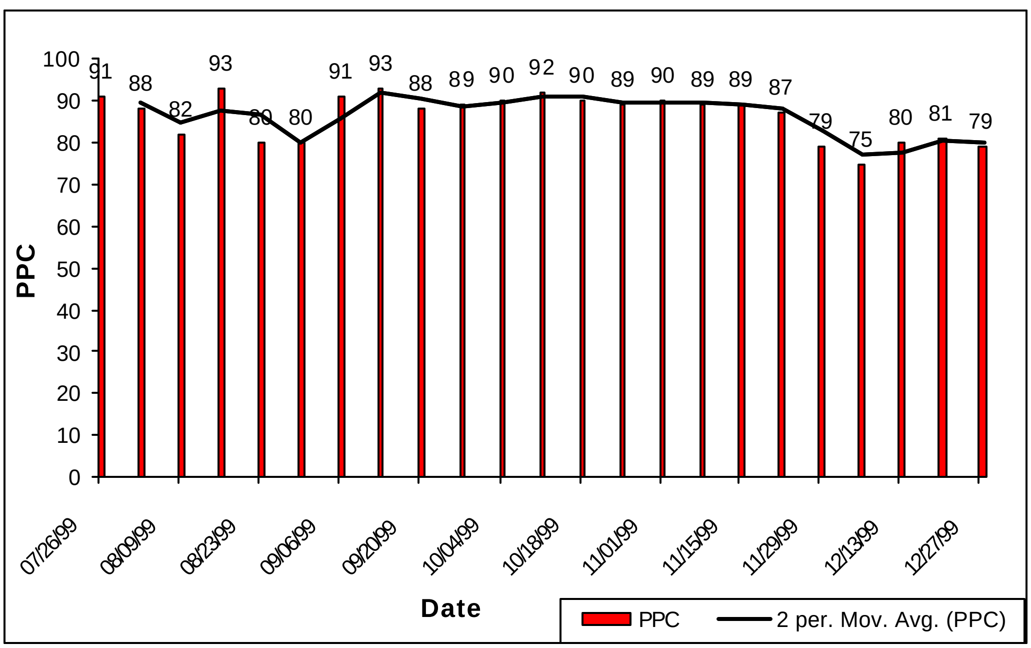

Figure 4.1. Percent Plan Complete (PPC) – Case A

Table 4.2 summarizes the root causes of failure to complete tasks. The root causes were identified by the project participants in every weekly lean meeting and after calculating the PPC. The total effect was scaled to 100% to show the frequency of root causes for all 49 weeks. Referring to the Table 4.2, the major root causes were manpower, make ready, material delivery, schedule accuracy, coordination, and rework. Among these, make ready and manpower were the primary causes for incomplete work.

Table 4.2. Root Causes of Failure – Case A

Root Causes	Frequency
Make Ready	29%
Manpower	27%
Schedule Accuracy	13%
Material Delivery	11%
Coordination	8%
Rework	7%
Equipment Delivery	3%
Weather	1%
Overcrowding	1%
Unknown Condition	0%
Contract Problems	0%

4.1.5 Strengths and Weaknesses

Strengths and weaknesses were identified by the project participants of case A. The major keys to lean construction learned by the participants from this project were reliability, developing manageable work packages, workable backlog, trust, cooperation and teamwork. In addition, lean construction helped the project to strengthen business relationships, improve cooperation on the job site, improve workflow and schedule, and to lower costs.

The strengths of lean construction observed from the interviews in this project are summarized below:

- Communication and coordination among the project participants was greatly improved.
- The project had little fluctuation in manpower.
- The lean process developed a strong relationship with the owner and created transparency in reviewing the project among the participants.
- The lean system required participants to document their needs as opposed to keeping them in their heads.
- Lean construction seemed to be able to provide customers better products and to beat project schedules.

The weaknesses were as follows:

- There were too many meetings and too much information that had to be discussed in the meeting.
- At the meeting it was difficult and wasteful to explain the whole construction progress and tasks to the owner and other trades who did not need to know one's work.
- It was sometimes difficult to make the owner understand the problems that occurred during the construction phase.

The requirements for lean implementation emphasized by the interviewees were as follows:

- There must be honesty and trust among project participants

- Management determined it was necessary to become more rigid in checking the planning and performance progress.
- Significant effort at the beginning of the job obtained the best performance overall.
- Designer's involvement in project was identified as crucial.

4.1.6 Questionnaire Responses

Table 4.3 shows the results of the questionnaire from the project team. There was quite an opposite response between the project manager and the project engineer in the managerial time and attention element. This seemed to be because of the various duties of each within their organization. The project engineer attended the lean meetings and updated the whole planning forms from the subcontractors every week. He compiled everything into documentation. Both agreed there was high job satisfaction and that the company employing lean construction would be highly competitive in the construction industry.

Table 4.3. Summary of Responses from the General Contractor - Case A

Question	Project Manager	Project Engineer	AVG	Remark
Managerial Time & Attention	1	5	3	Low is better
Job Satisfaction	5	5	5	High is better
Turnover & Absenteeism	1	3	2	Low is better
Competitiveness	5	3	4	High is better

* 1: much less or much worse, 3: about the same, 5: much more or much better

The subcontractors, expectedly, answered that there was better planning and coordination, and higher job satisfaction compared to other similar non-lean projects. They insisted there was significant improvement in involvement and commitment. In this project, they obtained higher productivity and had to do less fire-fighting and overtime. Table 4.4 shows the subcontractors' responses.

Table 4.4. Summary of Responses from the Subcontractors - Case A

Question	Mech. Foreman	Fire Protection	Mech. Plumbing	AVG	Remark
Planning & Coordination	5	4	5	4.7	High is better
Involvement & Commitment	5	5	5	5	High is better
Fire-fighting	1	3	1	1.7	Low is better
Productivity	5	3	5	4.3	High is better
Unplanned Overtime (OT)	1	2	1	1.3	Low is better
Job Satisfaction	5	4	5	4.7	High is better

* 1: much less or much worse, 3: about the same, 5: much more or much better

4.2 CASE STUDY B

This case study focused on the general contractor and major key subcontractors who were involved in the construction of a new community medical center. Interviews were conducted with project teams from the general contractor and three major subcontractor organizations. The project's weekly planning meeting, which was attended by the general contractor's superintendent and project engineer, and foremen from all three subcontractors, was observed.

4.2.1 Project Description

The project was a combination of a one- and two-story hospital with an integral four-story patient care unit, a six-story medical office building, and a central plant. The project was located in Texas. The hospital, patient care unit and medical office building had a structural steel frame with an exterior skin of imitation stone masonry units, synthetic plaster and individual window openings. The structure bore upon both bell bottom and spread footing foundations. The intention was to invite the community into the area to take advantage of the amenities including the conference center, jogging and walking trail around the lake, lakeside gazebo and terraced landscaping. When the researcher visited the project site, nine people from the staff of the general contractor and three key specialties (the mechanical plumbing foreman, electrical foreman, and structural steel foreman) were working on the site. The construction contract was a negotiated, Cost Plus Fixed Fee/Guaranteed Maximum Price contract with graded incentive bonuses. The construction contract was for approximately $55M and the construction duration was to be 18 months. The worker's status was union. The project was approximately 25% complete at the time of the site visit, and was somewhat behind schedule. The delay was caused by weather problems.

4.2.2 Results

Results were gathered from observations (the weekly planning meeting, PPC, root causes), interviews with project personnel, and collection and analysis of the short questionnaire survey. Results were focused on the lean planning systems, organization, attitudes, and contract.

4.2.2.1 PROJECT PLANNING SYSTEMS AND PROCESS

The project employed the whole Last Planner systems including master schedule, phase schedule, six-week lookahead, weekly work planning (WWP), and PPC. A construction planner and two-week lookahead were also applied to this project. The construction planner shows whether each task that will be assigned the next week is ready to go. It is a checklist that shows the status of the contract, design, submittals and prerequisites, and the availability of space, equipment and labor. It also includes comments and reasons for delay on each task. The project was using a two-week lookahead plan in addition to the six-week lookahead. The two-week lookahead schedule provided more flexibility and visibility to the planner to control and maintain weekly planning. The planner could predict and prepare work one week earlier, and could decrease uncertainties. At every meeting, the planner could easily obtain feedback and root cause failure through this visible form. One lean system, Just-In-Time (JIT), was not employed on this project due to the size of the project site that had enough space to provide warehouses for the subcontractors.

The weekly work planning meeting was held once a week (Tuesdays at 9:00 a.m.) and involved the following:

- Coordination meeting
    1. Review the old issues
    2. Discuss the issues of Safety, Quality and Productivity

3. Discuss new issues

- Lean meeting

1. Review the six-week lookahead schedule
2. Review and discuss the two-week lookahead schedule
3. Review the Construction Planner – identify what is “ready” and the reasons for delay
4. Review the previous week’s activities – what was completed, what was not, PPC
5. Discuss the reasons for incomplete activities

Even though the meeting was the fourth one on this project, it was held to 30 minutes in length. The lean systems were easily set up and started due to the members who had former experience in lean construction. They helped others understand and follow the lean system forms.

The Critical Path Method (CPM) was mainly used together with other lean planning systems under the pretext of keeping the owner’s requirements and the general contractor’s target schedule days. The CPM could not be eliminated from the scheduling, but rather was combined with the master schedule to reinforce the scheduling. However, it was not used as the main schedule control tool. Under the CPM, the general contractor provided the target days on the CPM against the tasks of each trade and then the subcontractors modified their tasks based on the CPM schedule provided. This method is in opposition to lean principles. Lean principles recommend that the subcontractors provide a workable plan first to the general contractor and then the general contractor combines schedules and develops the most possible schedule and target days.

4.2.2.2 ORGANIZATION

No training programs were officially provided. Some project team members from the general contractor had been introduced to lean principles by a company internal class. Only one staff member had experience with an external training seminar and a previous lean construction project. A subcontractor who had worked on a previous lean project was assigned to this project. He helped teach other subcontractors about the planning process and its requirements.

Lack of knowledge on lean concepts and principles was determined from the interviews with both the general contractors and subcontractors. Advanced training related to lean concepts and principles had not been provided continuously, so most people were inclined to use the lean planning systems, which are visible and easy to use. It does not require participants to understand fundamental concepts.

In general, lean construction improves coordination and communication between the general contractor and subcontractors and also among subcontractors. In this environment a good relationship among the participants is created. As a result, good planning through coordination and communication facilitates better work flows and an order by sequence of installation that minimizes interference.

Successful lean implementation seems to be dependent upon the individual who manages the project. At the previous lean project in which one of the project engineers in this project was involved, the project manager was a proponent of lean construction, managed the whole project schedule and encouraged others to follow lean principles. As a result, the project went well under lean construction. However, the superintendent of the current project disliked the change and preferred that the CPM managed the schedule. The superintendent drove the schedule as much as he could. Regardless, the project was currently on schedule.

Consequently, there was less communication and coordination between the general contractor and subcontractors and between the owner and subcontractors. The coordination among the subcontractors was, fortunately, maintained by working with one another as is the case in many traditional (non lean) projects.

4.2.2.3 ATTITUDES

The general contractor applied lean construction to this project for two reasons. One was that the general contractor thought it was a good tool to improve project performance. The other was that the owner of the general contractor company encouraged his employees to use lean construction. For this reason, the project manager was not concerned what method the superintendent used for scheduling. The project manager seemed to be interested only in whether the project was going well, good performance was being obtained, and the project was on schedule and on budget.

The general contractor staff members that were interviewed said that lean construction was nothing but a tool to improve current practices. It was not a new form of project management. Lean principles were the same as before, but were more focused on detailed planning through better coordination and communication among the participants. Lean construction was helpful for documenting, feedback and preserving historical data for use in future projects.

The subcontractors were more motivated by the last planner when compared to the subcontractors on projects not employing lean construction. They had better authority to schedule their own work and were able to attend the planning meeting as a representative of their company; hence, they seemed to feel self-fulfillment and achievement. However, several factors decreased the subcontractors' motivation. The superintendent dominated the schedule. There was a lack of enthusiasm to carry out lean implementation and a lack of involvement and commitment by the designer and owner. The superintendent's domination did not allow the subcontractors' full involvement in decision-making concerning their own work and commitment. The lack of involvement of the designer resulted in rework and caused the failure of work readiness and schedule accuracy.

4.2.2.4 CONTRACTS

There was no contract between the owner and the general contractor or general contractor and the subcontractors that identified full implementation of lean construction as a prerequisite for this project. The owner did not specify which systems were to be employed by the general contractor. The owner only wanted to obtain a final product on time and under budget with no problems. The subcontractors were optionally encouraged to use lean planning systems and to provide the results to the general contractor because the general contractor decided to employ lean systems.

4.2.3 Feedback from Interviews

The following is feedback from various participants interviewed by the researcher.

4.2.3.1 GENERAL CONTRACTOR INTERVIEWS

The project manager indicated that lean construction is a good tool. It helps others know what is happening to each other. It also helps obtain more proactive project management. The lean principles here were more focused on detailed planning through better coordination and communication among the general contractor and all subcontractors.

Material "Just-In-Time" (JIT) delivery may have both good and bad aspects. Pre-stocked materials may discourage the owner and designer's frequent design changes; however, if the owner and designer change their minds, cost is wasted. "More-In-Time" (MIT) delivery is good for the small sized project site, but the owner and designer may make frequent design changes because they do not need to worry about cost of wasted materials.

The first project engineer (I) had taken two lean construction classes. One was an internal training class and the other was an LCI seminar taken when he worked on a previous lean project.

The project engineer (I) commented that lean construction is a good tool for communication and coordination among the subcontractors. Through this communication, they know when and what they and others have to do. However, there is not enough time to obtain total agreement due to the difficulty of coordination.

The project engineer (I) seemed to be more motivated from the previous project under lean construction than the current project because of the mixed form of lean and traditional methods on this job.

If the site is small, MIT material delivery is preferable, however if the size of the site is big enough to stock materials, the project engineer (I) preferred use of a warehouse. This project had enough space for a warehouse, so the subcontractors had already delivered their materials to the warehouse.

The project engineer (I) commented that the weaknesses of the planning meeting were as follows:

- Repetition – Participants keep saying what others already know, and they keep showing the same schedule until the tasks on the schedule are completed (i.e., six-week planning).
- Meeting time – If time is not well-managed, it may take a long time. (1 ½ to 2 hours in length)

The second project engineer (II) took an internal company class for lean construction. He felt that the Last Planner looks like simple planning, so there is no confusion in understanding it. Lean construction is just a tool, which can be used for historical data to qualify subcontractors for future lean projects and to provide feedback to identify the reasons for incomplete planned work. It also provides good documentation.

Lean construction has no effect on laborers because they do not care about the concepts and principles. They just want to know what work they have to do for the day, and that's it.

The project engineer (II) claimed that the weakness of lean construction was that subcontractors might cheat the general contractor with the wrong planning and PPC. Thus, high reliability was required. The other weakness was that too much time was consumed in planning and scheduling, so the foremen's ability seemed to be a major requirement.

The third project engineer (III) believed that lean construction is more than a tool and can develop coordination and communication among subcontractors. It also brings the general contractor and subcontractors together to share information and goals. Through the planning meeting, everyone knows what they have to do and what others have to do. The weekly meeting is effective in producing these results.

The major benefit of lean construction is documentation. It makes everyone accountable to do what they need to do in an orderly work sequence.

4.2.3.2 SUBCONTRACTOR INTERVIEWS

This project was the first lean project for the electrical foreman, and there was no training from his company or the general contractor. A mechanical subcontractor foreman, who had experience with lean project, showed the electrical foreman how to make and fill out the last planner forms (six-week, two-week, construction planner, and PPC). He received several copies of the forms from the mechanical foreman, but did not know what to do. In his opinion, no one knew what to do if they received these forms without any training and education. Hence, he always asked for help from the mechanical foreman. The electrical foreman believed that education was absolutely necessary to understand the benefits that can be gained when the last planner system is followed. Instruction on how to fill out the last planner forms is critical too. There were no standard forms, so every form used by the general contractor and subcontractors was different. Thus, the electrical foreman wanted to have a simple computer-based software that could help him easily fill out last planner forms. The program should show material and manpower like the information provided in a Means Manual.

For the success of the lean construction, honesty is required, and without this honesty, the PPC may ruin everything. The measurement method of PPC is not reasonable. The electrical foreman commented that if the work was almost finished, with only 1-2 hours left prior to completion, it was still considered as non-completed work. The measurement is only indicated 0 % and 100%. Measuring PPC every week did not make sense. He indicated that measuring PPC twice a month might be better.

The electrical foreman had installed materials one week prior, but had to remove them due to a specification error and change. He had to wait for a response to his request for correct information, but was still forced to complete the work based on the CPM schedule. The rework could have been avoided if he could have waited for the correct information. As a result, the electrical subcontractor was behind schedule due to this rework plus weather delays.

The major reasons for uncompleted work to date were prerequisite work, failure of delivery, lack of manpower and weather.

The most difficulty he had experienced on this project was the requirement to initiate planning and scheduling, which the general contractor had originally been responsible for. There also seemed to be twice the paper work. He questioned why he needed to print out extra pages that were already known by others that were attending the meeting. The electrical foreman also indicated that he personally hated JIT delivery because he usually had to stock at least one week worth of materials on site for a buffer.

Lean principles sometimes caused work to be delayed. In electrical work, there were tasks with no standard and no code. It could be done based on experience and intuition. However, under lean principles, he had to follow the planning and wait for the response from the designer. For successful lean implementation, the designer's involvement to provide a quick response to a request for information (RFI) is absolutely required.

The mechanical foreman had full authority to make decisions for his own tasks. He was the only subcontractor who had experience in lean construction. The general contractor chose the foreman for this project to have him help others implement lean construction. He made the forms used on this project and provided many suggestions. He took two lean seminars before a former lean project from the LCI.

The mechanical foreman indicated that through the meeting, subcontractors can know what they need to do. The planning helps in the consideration of others. It facilitates knowledge of participants' involvement; thus, there are few interferences and over-crowding in the work place since every subcontractor can share in the others' schedules. They can schedule their workers at suitable times. Lean systems make it easy to figure out coordination problems and resolve them.

The greatest difficulty for lean implementation is that there is usually not enough design information to schedule and to plan work from the designer.

The two-week lookahead planning was used on this project. It was easy and effective in identifying the next week's work and updating each week's work. It provided the big picture of two weeks worth of work. One week planning did not provide enough opportunity for feedback.

The mechanical foreman preferred an on-site stockyard if the site size is big enough to have a warehouse. He knew that JIT delivery could prevent damage of stock materials, loss of materials, installation of materials in the wrong place and forgetting orders, and that JIT is necessary for the small size project. However, no one can be 100% sure about delivery promises.

The mechanical foreman commented that the pull schedule is better than CPM because everyone can be involved in planning together based on his/her realistic schedule.

More managerial time is required in lean construction than other traditional projects. However, spending more time in planning is a useful activity to prevent rework and to identify what is needed for the work to be done, what has to be completed for other trades, and to have other trades know what is needed to start work. In the case of the previous lean project, the mechanical foreman's company had dramatically improved productivity while reducing manpower in plumbing from the normal 30 to 13 workers to complete the work.

In the previous lean project, the planning meeting allowed all participants to have a chance to speak. In this project, the meetings were performed at random;

therefore, the meetings of this project were not as productive as the previous project.

The mechanical foreman intends to keep using lean systems, especially last planners, for his own benefit, even though other trades may not be using the lean principles. He plans to encourage other trades to use lean planning systems. He believes that these systems resulted in his best performance.

Compared to the previous lean project, he felt less job satisfaction, coordination and involvement due to the use of the CPM, which they had to follow. There was a lack of information and less communication between the general contractor and subcontractors.

The mechanical foreman was motivated by lean construction. He was proud because he was chosen for this project and recognized as a person who knows lean construction.

The structural steel erection foreman did not care about the systems used for the project management. He indicated that he had only one goal: erect structural steel and connect steel decks. He attended the weekly work plan meeting without any preparation. He needed to identify which deck portions were needed to be completed for the other trades' prerequisite works. To date there was a one week schedule delay due to weather conditions. The foreman cared only about material delivery and availability. He did not know what the term "lean construction" meant.

4.2.4 PPC and Root Causes of Failure

The role of the superintendent was primarily scheduling and coordination. He was the central person in coordinating the schedules and had over 17 years work experience. He created the project's lookahead schedules and the weekly planners for the general contractor's crews, and also coordinated the weekly planners for all subcontractors. Subcontractor foremen provided their own lookahead schedules and weekly work plans to the superintendent on Fridays for the following week. The foremen put a significant amount of effort into developing the weekly work plans. The foremen attended a weekly work plan meeting on Tuesday morning to review progress and coordinate the current week's work plan with the other trades. The foremen selected the work methods with input from the project superintendent. The project engineers attended the meeting, gathered the plans, calculated the PPC and identified the root causes of failure. After the meeting the engineer updated the plans and the PPC.

Percent Plan Complete (PPC) is measured and tracked as the main performance metric on the lean project. The contractor had measured PPC for a total of six months, and it had averaged 77%.

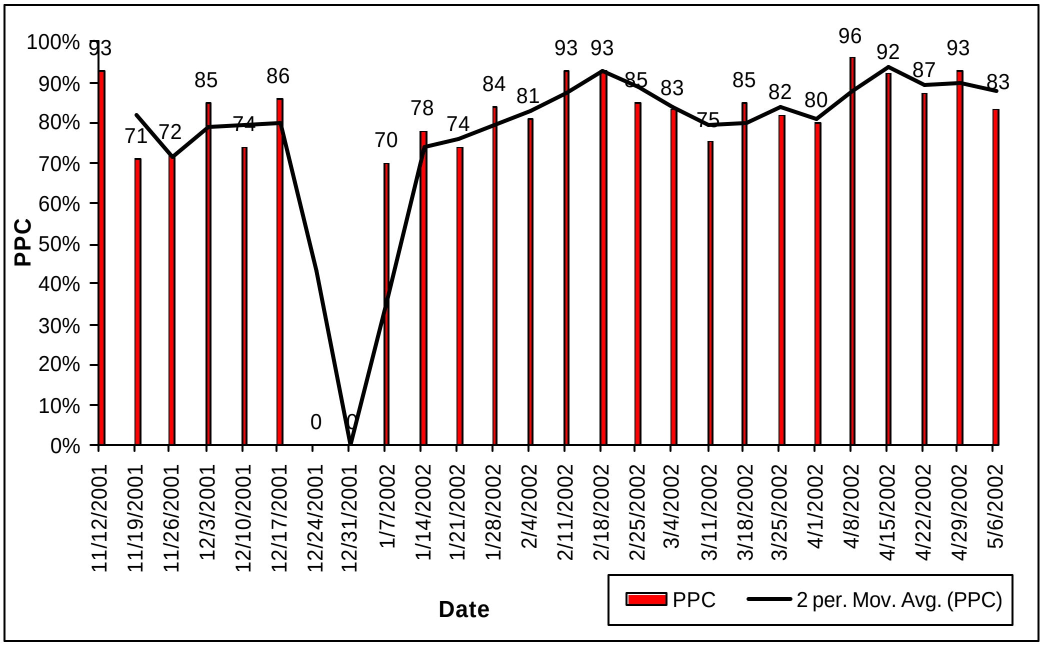

Figure 4.2. Percent Plan Complete (PPC) – Case B

If there were any assignments that were planned but not completed in a given week, root causes had to be identified to prevent repetition of these failures and promote continuous improvement.

Table 4.5 summarizes the frequency of identified root causes. From the PPC chart, 23% of work on average failed to be completed. The total effect was scaled to 100% to show the frequency of root causes. Referring to the Table 4.5, the major reason was identified as make ready problems. Others were weather, schedule accuracy, manpower, and design problems. As most participants claimed, the lack of the designer's involvement had important influences on failure of uncompleted planned work. Even though only 13% was attributed to design problems, it had a great influence on the other root causes. As shown in

Table 4.5, schedule accuracy problems, caused readiness problems, and manpower problems were occurred from the lack of getting information on time and also errors of design.

Table 4.5. Root Causes of Failure – Case B

Root Causes	Frequency
Make Ready	26%
Schedule Accuracy	21%
Weather	17%
Design Coordination	13%
Manpower	13%
Material Delivery	7%
Coordination	3%
Equipment Delivery	0%
Rework	0%
Unknown Condition	0%

4.2.5 Strengths and Weaknesses

The strengths of lean construction observed from the interviews in this project are summarized as follows:

- Compared to communication and coordination between projects not employing lean construction, the project participants felt that these efforts were greatly improved. The participants knew when and what they would do and what the others would do.
- The lean planning meetings tied the general contractor and subcontractors together to share comments and goals.

- Lean construction has the benefit of good documentation, and it can provide historical data to qualify subcontractors for future lean projects.
- Lean construction also makes it easy to obtain feedback to review the reasons of failure.
- Lean construction facilitated better work by matching manpower levels, materials and equipment. It also prevented over-crowding and interference in the work place.

The weaknesses observed from the interviews in this project are summarized below:

- The lean meeting was too repetitive, and it took a long time if not well-managed.
- The subcontractors could proceed with the wrong planning and PPC, thus an extra person who mainly maintains lean construction figures should be utilized.
- It was difficult for the subcontractors to initiate planning and preparing written schedules which had originally oriented to the general contractor. They just scheduled their work roughly using prior work experience, common sense and intuition. It must be emphasized that the general contractor has a responsibility to help the subcontractors plan and prepare detailed schedules.
- There were early difficulties in establishing the implementation details and forms. A need indicated by the subcontractor was the development of software to have standard forms exactly the same as those of the general contractor and the other trades. This software should support the

arrangement of materials and manpower for tasks. The software should be as simple as possible.

The major requirements for lean implementation emphasized by the interviewees were honesty among project participants and designer's involvement in project. If these could be obtained, the project would improve lean implementation.

4.2.6 Questionnaire Responses

Referring to the results of the short questionnaires, Table 4.6 received from the project teams of the general contractor, job satisfaction was high and participants anticipated that employing lean construction would be highly competitive in the construction industry compared to other companies not employing lean construction. They perceived no difference in managerial time and attention between the lean project and other non-lean projects.

Table 4.6. Summary of Responses from the General Contractor - Case B

Question	Project Mgr	Project Engr	Project Engr	Project Engr	AVG	Remark
Managerial Time & Attention	4	5	3	2	3.5	Low is better
Job Satisfaction	5	4	4	5	4.5	High is better
Turnover & Absenteeism	1	3	3	2	2.3	Low is better
Competitiveness	5	3	4	4	4	High is better

* 1: much less or much worse, 3: about the same, 5: much more or much better

Table 4.7 summarizes the answers from the subcontractors. According to the results, most subcontractors had good attitudes towards lean construction. However, two subcontractors unexpectedly indicated that planning and coordination were about the same compared to similar non-lean projects. One foreman was somewhat frustrated in his involvement and job satisfaction. The reason for this frustration was the superintendent's scheduling oriented to CPM. The foreman thought that the tight schedule pressure and enforcement of CPM reduced his involvement in planning and job satisfaction.

Table 4.7. Summary of Responses from the Subcontractors - Case B

Question	Elec. Foreman	Mech. Foreman	Steel Erector	AVG	Remark
Planning & Coordination	3	3	5	3.7	High is better
Involvement & Commitment	4	3	5	4	High is better
Fire-fighting	3	4	1	2.7	Low is better
Productivity	4	4	5	4.3	High is better
Unplanned Over Time	2	1	1	1.3	Low is better
Job Satisfaction	4	3	5	4	High is better

* 1: much less or much worse, 3: about the same, 5: much more or much better

4.3 CASE STUDY C

This project was a pilot project for the implementation of the Last Planner. The goal was to test if the implementation of the Last Planner method improved the control of production and the performance of the project.

Unfortunately, the owner of this project did not want to share the project information or allow others to investigate the project site. Thus, a site visit and face-to-face researcher-led interviews were not possible. However, thanks to the general contractor's coordination, interviews were conducted by the company itself and data was e-mailed to the researcher. For this reason, the format of data collection was different than with other project data collection, and the general contractor's interviews were not conducted. The general contractor summarized their overall lean performance in the project.

4.3.1 Project Description

The project scope included a 15,000 square foot process chemistry lab and office space tenant improvements within the second floor of an existing building shell, and approximately 2,000 square feet of new exterior electrical/mechanical space for a 1000 kilowatt generator, cooling towers, chillers, pumps, and associated equipment. The project also included an extensive upgrade of HVAC and electrical systems (including redundancy and capacity for future build out). The project was located in California. The project contract was approximately $5.5 million and the project duration was six months. The project was almost completed at the time contact was made.

4.3.2 Results

Results were gathered from interviews with subcontractors and from collection and analysis of the short questionnaire survey.

4.3.2.1 PROJECT PLANNING SYSTEMS AND PROCESS

The project employed a six-week lookahead, Weekly Work Plan, and PPC. The Last Planner process involved the following steps on a weekly basis:

- Monday: Collect information from foremen about the constraints of their upcoming activities and update the project schedule (GC team)
- Tuesday: Coordination meeting
    1. Review the previous week's activities—what was completed, what was not completed, PPC.
    2. Discuss reasons for incomplete activities.
    3. Review six-week lookahead and constraints, identify what is "ready."
    4. Develop Weekly Work Plan for the following week.
- Tuesday (but sometimes later): Distribute the WWP to foremen.
- Thursday: Distribute the six-week lookahead to subcontractors so they can prepare for next Tuesday's meeting.

4.3.2.2 OBSERVATIONS

The following observations of the overall project were distributed by the general contractor.

There were early difficulties in establishing the "system." The project team was dedicated to the implementation despite early difficulties, and developed a good system that was easy to use and up-to-date (once it was set).

Coordination meetings were held to one hour in length. The team improved the Planning Reliability. The PPC in Figure 4.3 was consistently around 80% the last few weeks. As the increased PPC shows, the project team got better in executing what they planned to do. In the action of planning and scheduling, the system forced the general contractor to plan in great detail and to be extremely disciplined with keeping and updating the six-week schedule. Subcontractors provided input regarding their work needs which forced some of them to better identify their needs.

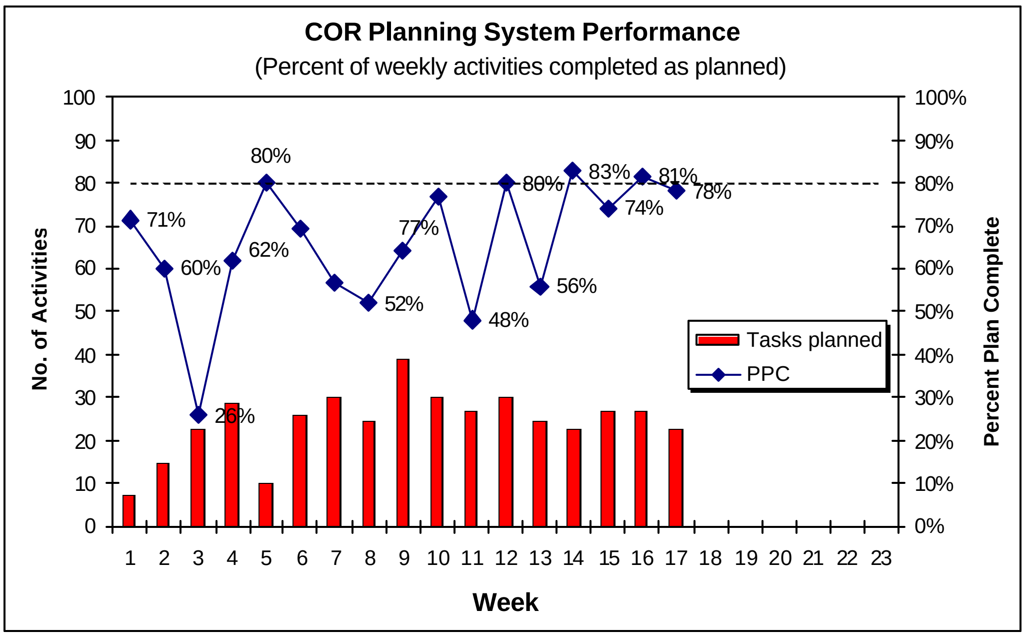

Figure 4.3. Percent Plan Complete (PPC) – Case C

The project had better coordination among subcontractors regarding pre-requisite work constraints (the detailed work sequence), and developed a good environment for cooperation. The team systematically identified and removed constraints that could delay work. There was much better communication of the weekly plan with responsibilities to all. The team reduced the "disconnect" between the general contractor's plan and the subcontractors' work.

For most subcontractors, their lookahead planning was not detailed enough. However, the constraint analysis was improved. Subcontractors often did not come prepared. They did not have much of the information they needed such as delivery time for critical material and equipment. Problems with information were often discovered after work had been started.

There was difficulty in securing "reliable promises" from the subcontractors in the coordination meeting. Some tasks stayed in the plan as "optimistic goals to shoot for" rather than positive "will do."

The project also had difficulty in determining exactly what work would be accomplished the following week. The project did not have a specific WWP every week. Part of the problem stemmed from not having all the "right" people present at all the meetings.

Subcontractors' commitments and declaration of completeness were needed. The project had limited root cause analysis of reasons for incomplete activities.

4.3.3 Feedback from Interviews

The key contractors' foremen and project manager were interviewed on November 9 and 13, 2001. The interviewees included the mechanical sheet metal foreman, mechanical piping foreman, mechanical start-up foreman, electrical foreman, plumbing foreman, and the mechanical project manager.

The company conducted interviews that were focused on the following four questions, and then analyzed the results based on each question:

1. Planning & Coordination: Compared to other similar projects, how was the planning and coordination on this project? 1 2 3 4 5 much worse somewhat worse about the same somewhat better much better

2. **Fire-fighting:** Compared to other similar projects, how much firefighting (unexpected urgent problems) was on this project? 1 2 3 4 5 much worse somewhat worse about the same somewhat better much better

3. **Unplanned overtime (OT):** Compared to other similar projects, how was the unplanned OT on this project? 1 2 3 4 5 much worse somewhat worse about the same somewhat better much better Approximately: unplanned OT vs. total hours What were the main reasons for unplanned OT?

4. **Productivity:** Compared to other similar projects, how was the productivity on this project? 1 2 3 4 5 much worse somewhat worse about the same somewhat better much better Approximately: actual hours vs. estimated hours. How did the coordination affect your productivity?

The summary of responses in Table 4.8 showed that the Last Planner System increased planning and coordination in the project, and less unplanned overtime and unexpected urgent problems were experienced. No productivity improvement was discovered in this project.

Table 4.8. Summary of Responses from the Subcontractors - Case C

Question	Mech. Sh-Mtl	Mech. Piping	Mech-Start Up	Electr	Plum	Mech PM	AVG	Remark
Planning & Coordination	4	4.5	5	3.75	4	5	4.4	High is better
Fire-fighting	2	2	2	4	1	4	2.5	Low is better
Unplanned OT	2	1	1	2.5	1	2	1.6	Low is better
Productivity	4	2	3	4	5	2	3.3	High is better

* 1: much less or much worse, 3: about the same, 5: much more or much better

The following shows the details from interviews with subcontractors, based on each question. Respondents described the benefits of lean construction and gave comments on opportunities for improvement.

4.3.3.1 PLANNING & COORDINATION

Contractor	*Score*	Benefits	Comments
Mechanical-Sheetmetal	4	On this job, knew what all subs were working on. Meetings communicated needs and addressed issues for following weeks. Communicated priorities.	All players need to communicate well, limited benefits if only few do it.
Mechanical-Piping	4.5	Recognized issues-got answers faster. Good cooperation between subs.	Too much work at the end of the job, but no work was in the way
Mechanical-Start-up	5	Unique coordination meetings on this job. Very well-organized, very useful. Helped work well with other subs.	
Electrical	3.75	Knowing what everyone will be doing was useful. More in-depth coordination and preparation. The "board-to-board" system was best.	Some scope not communicated well.
Plumbing	4	Coordination better than any other contractor.	Only problem early on, when working on wrong priority.
Mechanical PM	5	Challenging project, a lot of work in small space. Great planning and coordination. Got the plan on the table, addressed the issues. The flow was great.	Unforseen issues with existing systems

* 1: much less or much worse, 3: about the same, 5: much more or much better
** High score is better

4.3.3.2 *FIRE-FIGHTING*

Contractor	*Score*	Comments
Mechanical-Sheetmetal	2	Minor issues (not fires).
Mechanical-Piping	2	Some coordination problems mainly with own shop.
Mechanical-Start-up	2	Keeping existing equipment on line with minimum downtime (occupied facility). Some coordination issues with own subs
Electrical	4	Scheduling work with PG&E was a problem. Last minute scope from mechanical design. Near the end many things came up that were not in the plans.
Plumbing	1	No urgent issues.
Mechanical PM	4(+)	No fire-fighting from field coordination. Mostly issues with own start-up subs. Difficult to get realistic commitments and manpower. The fume hood problem was important "fire," but it was well-coordinated and maintained the flow.

* 1: much less or much worse, 3: about the same, 5: much more or much better
** Low score is better

*** (+) It is interesting that the mechanical project manager felt more "pressure" than the three mechanical foremen. Two probable reasons could account for this: first, he was less experienced with this type of project; second, he was under pressure to meet the field's requirements, and had many different constraints to address from suppliers, design (the mechanical part was design-build), design coordination, and start-up subcontractors.

4.3.3.3 UNPLANNED OVER TIME

In addition to asking the foremen, the general contractor also checked the company's log for change requests that subcontractors submitted over time.

Contractor	*Score*	Comments
Mechanical-Sheetmetal	2	No unplanned OT. Reasonable schedule, worked smoothly
Mechanical-Piping	1	Normal weekend shutoffs-No unplanned OT
Mechanical-Start-up	1	No unplanned OT
Electrical	2.5	1- About 110 hrs OT of approx. 4,000 total hrs < 3% 2- Fume hood wires not connected from shop-added RCE scope: 80 hrs OT 3- Lights: 30 hrs OT to release area.
Plumbing	1	No unplanned OT-only planned shut-downs
Mechanical PM	2	More than 3,000 hrs total. OT about 10%, 300hrs. OT due to occupied facility. Minimal OT due to emergencies or coordination problems.

* 1: much less or much worse, 3: about the same, 5: much more or much better
** Low score is better

4.3.3.4 PRODUCTIVITY

Contractor	*Score*	Benefits	Hours
Mechanical-Sheetmetal	4	Had areas ready to go. Good coordination. Checking "ready" work was good practice, very little "jumping around."	Approx: 4 x 10 wk = 40wk x 40=1,600 hrs
Mechanical-Piping	2	Some rework due to internal problems (+) No impact from other subs. DPR and subs very helpful on this job.	Approx. 1,000 hrs (800 since September)
Mechanical-Start-up	3	Some impact from Electrical design (lighting panel, low voltage)	Approx. 400 hrs
Electrical	4	Some impact from in-house coordination with design, and PG&E. On this job, very small impact from other subs. Did not have to jump around.	About 4,000 hrs
Plumbing	5	On this job, all knew what others were doing and where others were going to be.	Hours: 4 avg x 15wk =60 x 40 = 2,400
Mechanical PM	2	Given the complexity of the project, it was ok, but exceeded hours. Some problems with our own piping design created problems in the field. Some more hours for startup. Fume hood problem (ISEC) added work to our subs. No coordination problems-no negative impact.	Approx hrs (sm=1,300, pp=1,500, su=400)

* 1: much less or much worse, 3: about the same, 5: much more or much better
** High score is better

*** (+) It should be noted that the mechanical piping foreman who started the project was replaced halfway through the job due to lack of performance and difficulty in coordinating and working with other foremen (including the other mechanical crews-start-up and sheet metal).

4.3.4 Summary and Comments

The project team proposed some actions to prevent difficulties in lean implementation in the future. To prevent early difficulties in establishing the day-to-day implementation details and forms, the team suggested spending 20% of time on lean theory and 80% on “how-to” during the introduction of Last Planner. For the lack of detail for some project activities, it recommended to make an activity “breakdown” using the pull schedule. The subcontractors’ lookahead was not detailed enough because foremen did not have all the information they needed and did not get enough prompting from the general contractor. Project problems occurred with activities where the subcontractors’ planning was weak. To improve the subcontractors’ lookahead schedule, setting clear expectations and agreement in the beginning of the project, and gathering input from subcontractors’ project managers and suppliers should be absolutely required. The project manger and superintendent consistently required the weekly lookahead reviews with the subcontractors, and helped subcontractors’ foremen with lookahead schedule. The general contractor kept emphasizing the importance of high PPC (reliability), and identifying the reasons for incomplete work.

According to the subcontractors, the coordination of the work on this project was extremely successful. The project had its share of challenges. The coordination did not prevent design problems, or supplier errors, but helped the team deal with the problems effectively while maintaining the work flow.

Despite the project conditions (a lot of work by several contractors in a small area) and the unforeseen problems (mainly fume hoods, scheduling PG&E, and some electrical requirements that were introduced late), the work was well coordinated, and the work flow was maintained. No productivity problems occurred due to work flow and coordination.

According to the subcontractors, this type of project usually has a lot of coordination problems. On this job, the subcontractors did not identify any significant coordination problems. Some productivity issues were caused either by incomplete design, supplier problems, or manpower allocation. The coordination method made everyone a better "team player."

The last planner helped the contractors know: a) who will be doing what and where, b) what each one needs from the others, and c) what are the project priorities. The system itself created a more collaborative environment because it "demands" that the subcontractors address these issues.

Opportunity for improvement includes the need for more in-depth review of the design constraints in the six-week lookahead schedule. This can improve design management and align the design with field needs.

According to the data provided by the general contractor, this project had well-organized lean planning systems and properly implemented them enough to obtain successful results.

The general contractor conducted interviews with the subcontractors and focused on the benefits and opportunity for improvement of using the Last Planner. Effects of weekly lean planning meetings were investigated as well. However, this project was a pilot project for the implementation of the Last Planner, so it did not consider other factors such as contract, organization and attitudes of project participants. Thus, it was difficult to compare this project with case study A.

4.4 CASE STUDY D

This case study focused on an office renovation project. The project was small and the major tasks included internal finish work and changes in office layout. The construction company, typically a general contractor, acted in the role of the owner. This company hired a small general contractor and had that contractor chose other trades for the project. The owner-role company encouraged the general contractor to employ lean construction.

4.4.1 Project Description

The project was a renovation of a 1,000 square feet office building located in California. The major tasks included repositioning office partitions, thus increasing 23 office rooms to 27 office rooms, converting two conference rooms to six conference rooms, and one kitchen to two kitchens, upgrading mechanical and electrical facilities according to these layout changes, and renovating internal finish work. The construction cost was $1.1M. The construction contract was lump sum. There were two phases: phase one was a renovation using traditional methods and phase two employed lean construction. Phase two was in progress at the time of the site visit. During phase one and phase two, the building was occupied by the client. The construction duration totaled 8 ½ months: 5 months for phase one and 3 ½ months for phase two. There were two staff people on the site from the construction company assigned as the owner, and a superintendent from the general contractor. Most work on this project was subcontracted. The project had no contracts that required lean construction.

4.4.2 Results

The results were based on observations and interview with the project participants. Results focused on the lean planning systems, organization, attitudes, and contract.

4.4.2.1 PROJECT PLANNING SYSTEMS AND PROCESS

The project employed a master schedule, a six-week lookahead, and weekly work planning. The weekly lean meeting was held on Thursday. The project engineer from the owner company and the project manager of the general contractor attended the lean meeting. The meeting had not yet been formally arranged. The weekly lean meeting agenda included:

1. Check the last week's PPC.
2. Review planned work for the current week.
3. Solve problems caused from planned work for the current week.
4. Check work assignments for the next week.
5. Modify the six-week lookahead.

This project did not have the process for work backlog that would decide completeness of planned tasks, and ultimately success of the project. The lookahead and weekly planner were not detailed enough to keep and update the progress of the project. Just-In-Time delivery was not applied to this project. Most materials were already stocked at an off-site warehouse. The meeting was finished within 20 minutes.

4.4.2.2 ORGANIZATION

The owner company staff knew that the lean principles and systems would be beneficial and effective on this project, but could not force the general contractor to follow lean systems due to the size of the project, characteristics of project tasks, and qualities and attitudes of the general contractor and subcontractors.

The general contractor fully managed and controlled the subcontractors, so there was no communication between the owner-role company representative and subcontractors. Moreover, coordination and communication among subcontractors did not occur on the project.

Even though the owner-role company staff and the general contractor had a lean meeting every week, it was doubtful that the general contractor actually executed the work according to the lean planning provided. As in case study B, the general contractor mainly used the CPM to keep his own schedule, and updated the lean schedules to satisfy the owner. Satisfying the owner's requirements should be reason enough for using lean systems, but lean systems were not well implemented. Furthermore, lean systems should improve performance, productivity, and save money for the owner.

4.4.2.3 ATTITUDES

Fundamentally, the subcontractors with whom the researcher met on the site did not know lean construction, not did they realize the project had employed lean construction principles.

Most subcontractors' tasks on this project were simple, easy and repetitive; hence, they did not care which method was chosen for this project and did not see the necessity of communicating, coordinating and participating in decision-making.

Since phases one and two had to be built while the building was occupied, a requirement of this project was to reduce noise and client disturbance. Therefore, the project required much overtime.

4.4.2.4 CONTRACT

As in case study B, the owner company had no contract with the general contractor to employ lean construction; hence, the owner encouraged the general contractor to use lean systems, but could not enforce the general contractor to follow all of the lean ideas and systems.

4.4.3 Feedback from Interviews

4.4.3.1 OWNER-ROLE COMPANY STAFF INTERVIEWS

The owner's project manager was one of the instructors who taught lean construction in the internal company education program. He provided the researcher a copy of the lean job site handbook used for his company's internal education. The purpose of this handbook was to provide field teams with a guide for conducting lean construction work planning meetings and to show the benefits of these work planning meetings using the Last Planner management system. It included the Weekly Work Planning cycle, meeting summary, construction planner, and other sample forms.

The project manager insisted on the benefits and weaknesses of lean construction. The benefits he found were the improved coordination among project participants and their involvement in planning, and the ability to obtain faster feedback. The weaknesses were that despite the fact that the system itself was sound, there needed to be some mechanism for material delivery.

The project manager commented that lean construction systems, themselves, were easy to understand, but lean implementation in connection with lean theories was difficult. The project manager stated that everyone initially believed that lean would not make much of a difference, but they quickly saw the potential to revolutionize project success. Generally, people do not like to try new things when no one knows whether it will be a success or failure. People are concerned that their careers can be damaged by trying new things which may have risks. However, if people first try and accept the new thing with an open-mind, and then, start with a positive attitude then they learn that lean will work.

He personally preferred JIT delivery and saw the necessity of forcing people to use lean construction and partnering. His company sometimes forces its subcontractors or suppliers to accept lean ideas if they want to keep working with the company.

He suggested several options to have others use lean construction. If the company makes it a requirement to use lean construction for promotions, bonuses or other incentives, everyone will start to use lean. If everyone can be promoted and get bonuses or other benefits even though they do not apply lean, no one wants to change. Finally, encouragement, support and enthusiasm from the upper level of the organization are essential factors to adapt lean to the construction industry. Younger engineers more easily accept lean construction principles than senior engineers.

With lean, subcontractors can keep their manpower consistent, without fluctuation and with less manpower than with traditional management. Subcontractors are better able to use their resources. As a result, they are able to work more intelligently and to lower overall costs.

The owner's project engineer had attended two lean training sessions: one from the company internal program, and the other from the LCI. In this project he was skeptical about employing lean construction. He thought that the project size was too small, and the tasks were too simple, easy and repetitive, so he insisted that lean ideas were not adequate for this kind of project.

4.4.3.2 GENERAL CONTRACTOR INTERVIEW

The general contractor's project manager did not care about lean construction management and had no training related to lean construction. He made the lookahead schedule and weekly plan with the forms the project engineer provided. Since he had used the six-week plan, which was actually the six-week lookahead schedule, he understood the forms.

Even though he did not understand lean construction, he pointed out that the benefits of lean construction would be to find and remove constraints prior to the start of a work. In a large project, the owner could easily see and understand project progress.

The general contractor's project manager preferred six-week planning because he had used similar planning before. However, he was hesitant to accept weekly work planning. He felt that the tasks in this project were simple and repetitive and did not require weekly work planning.

4.4.4 PPC and Root Causes of Failure

The project was 35% completed at the time of the site visit, and its average PPC for a total of 6 weeks was 76%. Figure 4.4 shows the PPC and its trend line.

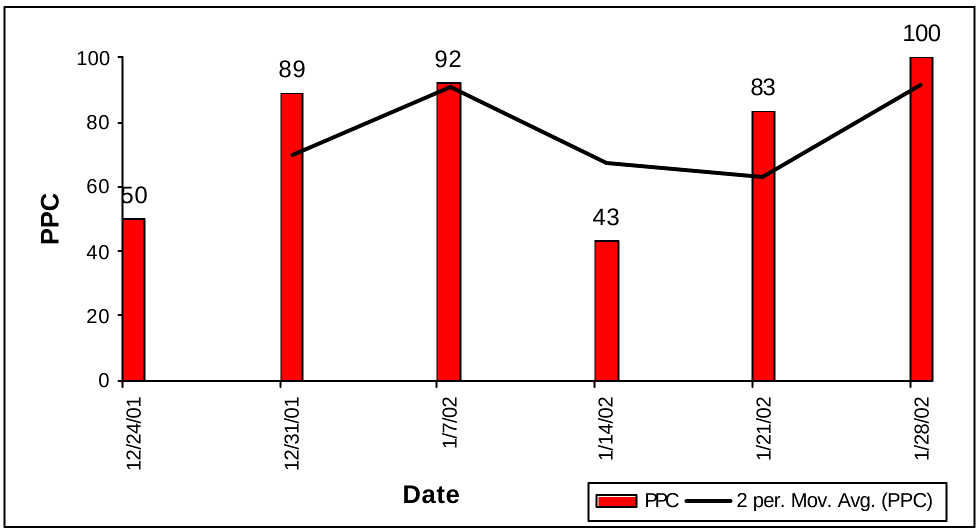

Figure 4.4. Percent Plan Complete (PPC) – Case D

The major root causes for failure to complete tasks were due to material delivery (45%), manpower (25%), and make ready (23%). Table 4.9 shows the frequency of the root causes. The lack of a workable backlog was one of the root causes in this project that caused many problems in scheduling material delivery, making work ready, and matching manpower to the schedule. Another problem was that the general contractor's project manager managed all subcontractors work and their needs alone. Even though it was a simple and repetitive project, one person could not totally handle all the subcontractors' needs for their work.

Table 4.9. Root Causes of Failure – Case D

Root Causes	Frequency
Material Delivery.	45%
Manpower	25%
Make Ready	23%
Schedule Accuracy	7%
Weather	0%
Equipment Delivery	0%
Design Coordination	0%
Rework	0%
Unknown Condition	0%
Client decision	0%

4.4.5 Strengths and Weaknesses

The strengths of lean construction identified by the owner-role company staff, which was not related to this project, were as follows:

- Improve coordination among the project participants and their involvement in planning.
- Obtain faster and reasonable feedback.
- The lean planning systems provided a short punchlist to check things that can be easily missed.
- Lean would find and remove constraints prior to the start of work, and make the owner easily follow the project progress.

The weaknesses of lean construction were that lean principles did not seem to fit this type of small, easy and repetitive project, and that more project participants such as subcontractors needed to be involved in the lean meeting and problem solving.

4.4.6 Questionnaire Responses

In spite of the unfavorable project conditions, the project team of the owner company showed good job satisfaction and they were convinced of the competitiveness of lean construction in the construction industry. They believed that less managerial time was needed in this project. Table 4.10 summarizes the responses of the project team members.

Table 4.10. Summary of Responses from the Owner-Role Company Staff - Case D

Question	Project Manager	Project Engineer	AVG	Remark
Managerial Time & Attention	2	2	2	Low is better
Job Satisfaction	4	5	4.5	High is better
Turnover & Absenteeism	2	N/A	2	Low is better
Competitiveness	5	3	4	High is better

* 1: much less or much worse, 3: about the same, 5: much more or much better

The subcontractors did not care which methods and systems were employed on the project. They followed their own schedule (or the work sequences and orders provided by the general contractor) and wanted to keep doing their assignments at the work place as given to them by the general contractor. The project manager assigned to the general contractor gave good scores to the planning and coordination, involvement and commitment, less rework and wasted time, and less unplanned overtime. However, he gave a low score to job satisfaction. The reason was the project was too small in size, and the tasks were too repetitive and simple. Table 4.11 shows the responses from the general contractor's project manager.

Table 4.11. Summary of Response from the General Contractor - Case D

Question	Project Manager in General Contractor	Remark
Planning & Coordination	4	High is better
Involvement & Commitment	4	High is better
Fire-fighting	3	Low is better
Productivity	3	High is better
Unplanned OT	2	Low is better
Job Satisfaction	2	High is better
Rework	4	Low is better
Resource Availability	3	High is better
Working Conditions	3	High is better
Wasted Time	2	Low is better
Work Assignments	3	High is better

* 1: much less or much worse, 3: about the same, 5: much more or much better

4.5 CASE STUDY E

This case study focused on a general contractor and major key subcontractors who renovated a women's health center. Interviews were conducted with project teams from the general contractor and two major subcontractor organizations. The project's weekly planning meeting, which was attended by the general contractor's superintendent and project engineer, and foremen from all three subcontractors, was observed.

4.5.1 Project Description

The project was a medical building renovation project that had a total of 59,000 square feet, two stories and a basement. The project was located in Michigan. When visiting the project site, three staff people from the general contractor and five subcontractors (the mechanical foreman, plumbing foreman, electrical foreman, ceiling & partition foreman, and insulation foreman) were working on the site. The construction contract was lump sum, approximately $8M in cost and 13 ½ months in duration. The workers were all union. There were two meetings held at the time of the site visit; one was between the owner and the general contractor, and the other was the weekly lean planning meeting. The general contractor provided strong educational programs in lean construction for the company employees, and developed class packages. These class packages are summarized in the 'Organization' included in the following 'Results' section. The lean planning systems were applied to the project six months after starting construction.

4.5.2 Results

The results were based on the observations, the course packages of the company and interviews with the project participants.

4.5.2.1 PROJECT PLANNING SYSTEMS AND PROCESS

This project employed the master pull scheduling, lookahead planning, weekly work planning, and JIT. Since the project was controlled by the CPM, the master schedule was easily produced based on the CPM. The weekly lean meeting was held every Thursday at 1:00 p.m. and it took normally thirty minutes to an hour. On Monday, weekly work schedules for the next week were submitted by the subcontractors to the general contractor's superintendent. The superintendent summarized the schedules and at the lean meeting modified the overall schedule according to each subcontractor's requirements and necessities.

This project referred to the weekly work plan meeting as the field coordination meeting. Most subcontractors attended the field coordination meeting, but many did not seem to be interested in the meeting with the exception of one or two subcontractor foremen. They looked bored and were not eager to participate in team communication, and merely answered the superintendent's questions related to their tasks.

The project had its own form for the meeting and for the paper forms used for lean implementation: the lookahead schedule, weekly work planning, and PPC chart. Since they had not initially applied lean systems to this project, however, there were many complaints about the new systems. The general contractor and subcontractors questioned why the project suddenly had to change its systems. Thus, the project was at the stage of the project teams trying to apply lean systems one by one.

4.5.2.2 ORGANIZATION

The general contractor has strong educational programs. The company requires employees to attend training programs at least 40 hours per year. One of the training courses is known as 'Lean Construction'. The company offers eight hours of lean training twice a week, and employees may attend the courses if they want. All company employees must attend a lean course at least once. In the course, the company generally introduces lean history, the lean concepts and principles, and lean planning systems. The company develops its direction and vision for lean construction in the course package.

The company is in the process of beginning to implement lean concepts as part of its project delivery systems. The company has a 'Lean Construction Steering Team' that leads the implementation of lean principles corporate-wide by utilizing teamwork and relentless commitment. This becomes sustainable through the cultural change of the company stakeholders.

The company considers using lean construction concepts along with other lean manufacturing concepts. Eight types of waste identified include over-production, inventory, transportation, waiting, motion, over-processing, correction, and not utilizing human resources. Over-production means producing over the customer requirements and producing making unnecessary materials and products. Inventory is holding or purchasing unnecessary raw supplies, work-in-process inventory, or finished goods. Transportation waste includes multiple handling, delays in material handling, and unnecessary handling. Waiting includes time delays and idle time. Motion includes extraneous actions of people or equipment that do not add value to the product. Over-processing is unnecessary processing steps, work elements or procedures. Correction is producing a part that was scrapped or requires rework. Finally, not utilizing human resources is not following-up and implementing ideas and suggestions.

The company applies the five 'S' steps for implementing a visual job site: <u>S</u>eparate/Scrap, <u>S</u>traighten, <u>S</u>crub, <u>S</u>ustain/Standardize and <u>S</u>ystematize. The first step is ‘Separate/Scrap,’ meaning sort out and remove all materials, tools and equipment from the work area that are not necessary to do the job. ‘Straighten’ means determine the most logical location for all the remaining necessary items using location indicators, labels, signs and others. Third is ‘Scrub,’ indicating clean and inspect the work area. Fourth is ‘Standardize’ or determine how to make the first 3 S’s part of everyone’s job (daily, weekly, monthly tasks, roles and responsibilities). Finally, ‘Systematize’ is to assess effectiveness to promote adherence and to improve workplace standards.

The company also considers ‘Value Stream Mapping’ as a lean fundamental. Its definition is the collection of all activities required to produce a product. All activities include those that add value and those that do not.

The company’s implementation and compliance to the standards established by the ‘Project Logistics Plan’ are one of the tools by which the company drives improvement through the use of lean construction techniques. The standards coupled with other lean tools and techniques can lead to the identification, control and elimination of waste. Each part of the ‘Project Logistics Plan’ has a specific intent and is integral to the process.

- The Site Logistics Plan directs the team to focus on front end planning of all resources and contract requirements.
- The 5S Audit Checklist provides the weekly discipline to maintain conformance of the requirements.
- The Visual Management tools provide the continuous reminders of the requirements and expectations.
- The Measurable provides the data required for continual improvement.

The measurable for the 'Project Logistics Plan' is how well the stakeholders abide by the expectations of the plan. One simple measurement is to track 5S Audit Checklist results. The 5S Audit Checklist is shown in Appendix A. The goal is to have no "Disagrees" in the score. The subcontractors and the general contractor's superintendent tracked their progress from week to week against this measurement. Results of the weekly 5S Audits were discussed at the subcontractors meetings. Measurement was reinforced in the course package with the quote, "You cannot improve what you cannot measure."

However, while the general contractor staff had taken at least one lean training course, the subcontractors did not take any training. The instructor for the general contractor randomly came to visit the site, and at the time of the site visit he/she provided simple lessons.

Traditional union problems existed in this project. All trades held their own ground. They were concerned about their own job securities and tried to be involved in as many activities as they could fit in their tasks. There were even arguments over identifying which work was included in which trade.

4.5.2.3 ATTITUDES

The representatives of the owner were negative toward lean construction. They wanted to have a meeting once a week. Whenever they met with the general contractor, they discussed the project from their own perspective. As with most traditional organizations, they just wanted to direct the general contractor to follow their orders without communication and coordination.

This project had union problems. The union had their own policy and usual practices and it was difficult to motivate union craftsmen. At first when the company introduced the lean concepts and encouraged using lean systems, the subcontractors agreed to participate. However, after a while, the subcontractors were hesitant to use the lookahead schedule, weekly work plan, or PPC. The union workers basically did not change their usual practices, so lean ideas were just added to their work load and this situation required the craftsmen to need more time and complete more paper work. They had low involvement and commitment, and there was no contribution to lean planning meetings.

The superintendent of the project was not motivated by lean construction. He admitted that lean construction was an advanced theory among other traditional theories, but claimed that it was just an academic theory. He thought that lean construction could not work on construction projects because it came from manufacturing. He had difficulty in applying lean construction to this project site because lean construction was applied six months after the project started with traditional practices and systems.

4.5.2.4 CONTRACTS

Similarly to case study B, C, and D, this project had no contract between the general contractor and subcontractors to require implementing lean construction. The project engineer on this project commented that there had to be a contract related to employment of lean construction to make the subcontractors more involved in planning and commitment.

4.5.3 Feedback from Interviews

4.5.3.1 GENERAL CONTRACTOR INTERVIEWS

The project manager observed that lean construction seemed to be affected largely by human resources. It was difficult to get qualified subcontractors involved with lean construction requirements. The PPC could be manipulated if the subcontractors were not truthful, so it required assigning the right person to measure it.

The benefits obtained from lean construction were open communication and feedback. The weakness was it was difficult to force the keeping of promises among project participants.

Education is an important factor in lean construction. The project manager believed that better job security should be guaranteed to employees who accept lean principles, understand and implement lean concepts and systems, and have experience in lean projects.

The project engineer indicated that the project employed JIT delivery. If there was a missing delivery and delay of work, it was the subcontractor's responsibility. The project engineer observed that subcontractors did not like the JIT delivery due to the lack of reliability of their suppliers. Thus, better coordination between subcontractors and suppliers had to be strongly encouraged.

He found that the benefits of lean construction were communication between subcontractors, faster and better feedback after planning was completed, predictability for upcoming work, and ease of handling of the whole project. However, lean might be too dependent on the quality and attitude of subcontractors. He thought setting workflow in the beginning was the most difficult part in lean implementation, hence the company recommended obtaining data from subcontractors to improve workflow.

The CPM was used together with lean planning systems. The company first considered the owner's requirements and based on this, the schedule was confirmed. To fulfill the owner's requirements, the CPM had to exist to keep the schedule.

The project superintendent had 37 years experience in the construction industry. He also had an open-mind to accept changes. However, he was negative about employing lean construction on this project. He felt that if lean had been initially applied to the project, it would have been better. He also thought the lean construction could properly work in a project that had full information, complete design, and repetitive work.

Even though the company encouraged employing lean construction, it seemed not to be working in this project. Lean construction needs coordination, communication and cooperation between subcontractors, but the subcontractors were intent upon increasing their tasks and earning more money. The project manager and engineer encouraged the subcontractors to use lean concepts and planning systems and tried to use lean by themselves. However, on this project, the subcontractors did not care about lean construction principles. They did their jobs according to the usual practices.

The superintendent said that this project made the subcontractors tired. The internal designs had much diversity in the details. For instance, all partitions had large windows of different shapes. In addition, there were many changes and design errors which wasted time in the daily schedule by having to solve the problems associated with changes and incorrect designs.

4.5.3.2 SUBCONTRACTOR INTERVIEWS

The ceiling and partition foreman was the most excited about lean construction. He thought lean construction seemed to be a good tool. The benefit was that it provided a better problem-solving process, goals and better coordination among the project participants. It was useful for trouble shooting for it showed why things went wrong.

The foreman thought lean concepts and systems seemed to be oriented to the subcontractors. Lean concepts had to be reinforced to derive more upper level support and involvement. The owner did not understand the difficulties of subcontractors. Thus, the general contractors had to endeavor to have the subcontractors and the owner understand the importance of better coordination and communication.

The mechanical plumbing foreman had no enthusiasm to accept lean construction. Even though the general contractor encouraged using lean, he did not care and just followed his usual practice. He said employing the lean systems was optional, so it could not hurt him if he followed the basic requests relative to lean given to him by the general contractor. He commented that lean construction looks good, but requires more paper work and managerial time. He doubted that lean construction could properly work on real construction sites.

The electrical foreman also did not care about lean systems. He wanted to keep his own schedule. He attended the lean meeting, answered the questions the superintendent asked, and then checked whether his tasks could be affected by other trades. He only thought of other trades' effects on his schedule, and never thought of his effects on the others' schedule. He did say, however, that lean planning such as the lookahead schedule, weekly planning, and PPC should be workable in the construction field. However, he did not think anyone wanted to talk about the lean concepts and principles.

4.5.4 PPC and Root Causes for Failure

The project was approximately 45% completed, and the PPC average for a total of 13 weeks was 59%, which was a lower score compared to those of other case studies. The PPC chart in Figure 4.5 indicated the average PPC estimated based on all subcontractors' reporting.

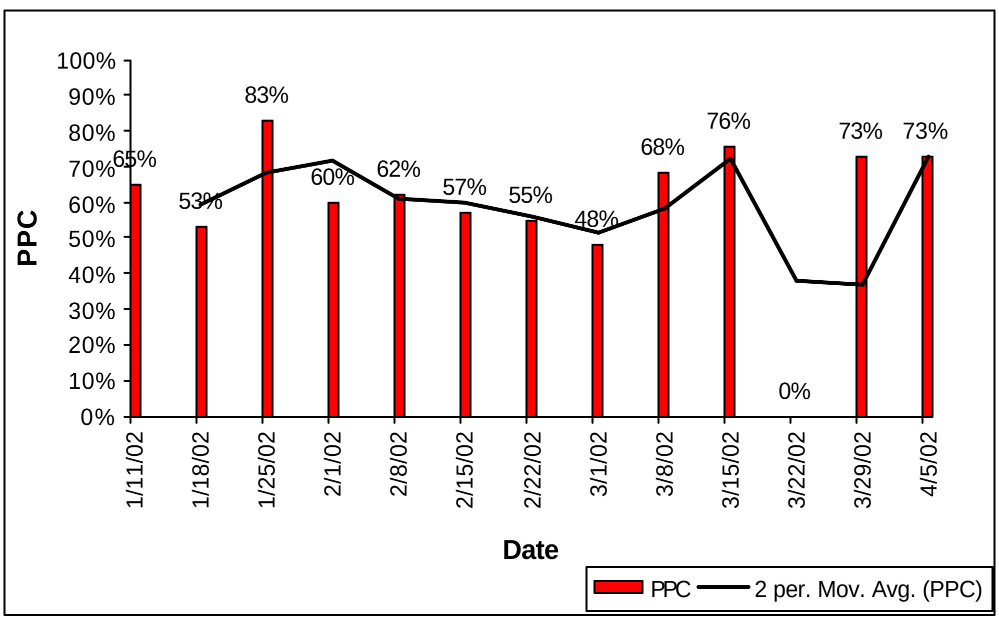

Figure 4.5. Percent Plan Complete (PPC) – Case E

Table 4.12 summarizes reasons for plan failure. The root causes were identified by the project participants in every weekly lean meeting and analyzed after calculating the PPC. The total effect was scaled to 100% to show the frequency of root causes for all 13 weeks. As shown in Table 4.12, the major root causes for plan failure were pre-required work and manpower. Both Figure 4.5 and Table 4.12 were based on the reports provided by four major subcontractors at the time of the site visit.

Table 4.12. Root Causes of Failure – Case E

Causes	Frequency
Pre-Required Work	34%
Others	29%
Manpower	17%
Re-directed by owner/CM/GC	5%
Material	5%
Interference	3%
Weather	3%
Drawings	3%
Equipment	1%

4.5.5 Strengths and Weaknesses

Strengths and weaknesses were identified by the project participants of case E. The strengths of lean construction that were observed were open communication, faster feedback, predictability for the next upcoming work, and ease in driving the whole project. Lean construction provided better problem-solving, better coordination, and effective trouble shooting.

The weaknesses of lean construction that were observed were the difficulty of keeping promises and the dependence of the project upon the quality and attitude of subcontractors. Lean planning systems demanded more paper work and managerial time.

The requirement for lean implementation was continuous education. Lean should work better where a contract requires full implementation of lean construction and provides required information, complete design, and repetitive work. More upper level involvement and assistance is required for better coordination and open communication.

4.5.6 Questionnaire Responses

Table 4.13 summarizes the responses of the general contractor's project team. Late employment of lean construction in this project made the project team have low job satisfaction and scored the lowest among all cases studied. Fortunately, the project team still had a good reputation for lean construction, so the score for competitiveness in lean construction in the construction industry was higher than average.

Table 4.13. Summary of Responses from the General Contractor - Case E

Question	Project Manager	Project Engineer	Project Superintendent	AVG	Remark
Managerial Time & Attention	4	3	3	3.4	Low is better
Job Satisfaction	2	3	3	2.7	High is better
Turnover & Absenteeism	3	1	2	2	Low is better
Competitiveness	4	5	3	4	High is better

* 1: much less or much worse, 3: about the same, 5: much more or much better

The scores shown in Table 4.14, expectedly, indicated that subcontractors thought that lean was no different from the projects not employing lean construction. The major reasons seemed to be due to the attitudes of the project participants toward lean implementation and the confusion and frustration of system changes during the construction period. Other reasons were due to the common problems that stemmed from union relationships, design omission and errors, lack of information and unanswered questions.

Table 4.14. Summary of Responses from the Subcontractors - Case E

Question	Ceiling & Partition Foreman	Plumbing Foreman	Electrical Foreman	AVG	Remark
Planning & Coordination	3	3	4	3.4	High is better
Involvement & Commitment	3	3	3	3	High is better
Fire-fighting	4	2	3	3	Low is better
Productivity	3	4	2	3	High is better
Unplanned OT	3	3	3	3	Low is better
Job Satisfaction	2	4	4	3.4	High is better
Rework	3	2	4	3	Low is better
Resource Availability	4	4	4	4	High is better
Working Conditions	3	4	4	3.7	High is better
Wasted Time	3	2	3	2.7	Low is better
Work Assignments	3	3	4	3.4	High is better

* 1: much less or much worse, 3: about the same, 5: much more or much better

4.6 CASE STUDY F

This case study was the most difficult study to assess the use of lean construction. The project had a significantly different work circumstance compared to the other case study projects. The study focused on interviews with four people from the general contractor and three major subcontractors, the mechanical foreman, electrical foreman, and drywall foreman. The project manager was not available, but five in-house staff persons were on site at the time of the visit.

4.6.1 Project Description

The project involved converting an old cookie factory into a college medical center in Texas. There were as yet no contracts, budgeted costs, or schedule for the project. The owner negotiated with the general contractor and sent a ‘Letter of Intent’ and initially gave the general contractor $5M for the project. The general contractor negotiated and hired subcontractors, but there were still no written contracts. It was a risky project for both the general contractor and subcontractors.

There were two representatives available from the owner. The detailed drawings were not provided, causing loss of time waiting for new information and drawings, plus analyzing the drawings already provided.

The subcontractors were mostly union. The superintendent of the project had 47 years of work experience. He divided the project site into five job areas and facilitated each trades’ tasks according to these areas. The project manager had project experience utilizing overseas lean construction principles. He knew lean concepts and principles and knew how lean planning systems worked as well.

4.6.2 Results

The results were based on the observations and interviews with the project participants.

4.6.2.1 PROJECT PLANNING SYSTEMS AND PROCESS

The project applied the master schedule with the CPM, weekly work plan, and PPC. A meeting was held once a week on Friday. It was supervised by the project superintendent and usually took 30 to 45 minutes. The subcontractors provided bi-weekly work plans to the superintendent at the meeting. The superintendent modified the schedule, confirmed work assignments for the next week, and calculated the PPC for the week. There was no work backlog for the work ready. The PPC was calculated and the results were shown, but there were no root causes of failure identified after measuring the PPC. Feedback could have prevented the failures to complete. JIT delivery was not considered at all. Lean planning systems could not be effectively working due to the characteristics of the project.

The bi-weekly work plan was used as both the lookahead schedule and weekly work plan. However, it did not provide work backlogs and detailed reasons for variance. There was no constraints analysis. One purpose of lean construction is to prevent variance before the work starts. Thus, the workable backlog is needed and constraints analysis is required. The project did not perform these activities at all.

Outwardly the project employed lean concepts and planning systems, but they were not working effectively on this project. The superintendent used his own CPM based upon Microsoft Planner. Based on the CPM, he modified the subcontractors' schedule and confirmed work assignments.

4.6.2.2 ORGANIZATION

The training situation was the same as with the other case studies. The project manager had lean experience in the United Kingdom, and the mechanical engineering project engineer (MEPE) had successful lean experience on a previous project. They knew how to implement lean construction and understood the benefits.

As in case study B, the project manager entrusted the management of the project to the superintendent. The superintendent seemed like an open-minded person to accept change, but already had assumed the traditional management style. At the weekly meeting the superintendent facilitated and allocated the trades' tasks to the appropriate work places and sequences, and ordered what the subcontractors needed to do based on the required date of completion. He controlled the meeting and gave the subcontractors work assignments in traditional styles.

The owner did not care about what project management type was employed on the project as indicated in the other cases except case A.

4.6.2.3 ATTITUDES

The superintendent exhibited strong leadership developed through his years of construction work experience. He knew how to control the subcontractors, how to solve problems that occurred, and how to manage workflow based on his work experience. He effectively facilitated the subcontractors' activities and manpower requirement plus how the work sequence was to be followed. The subcontractors knew that the superintendent had impressive work experience, hence they trusted and respected the superintendent. They said the superintendent made their work easy under this difficult project. However, this strong leadership did not allow lean construction to work well on this project. The subcontractors were extremely dependent on the superintendent and followed his orders due to their trust in his capability. The general contractor's staff person insisted that there could be less communication and coordination between the subcontractors. That is, the subcontractors should be passive and have less involvement and participants in decision-making.

The subcontractors had to provide reasons for variances on the bi-weekly work planner. All reasons were indicated as 'work to conclude next week.' The subcontractors should have provided more detailed reasons for variances, but believed that the superintendent should understand their problems.

The project engineers had enthusiasm to implement lean construction, but did not know what to do. Even though one of them took a training session, he did not know how to use lean planning systems because he had learned only theoretical concepts.

4.6.2.4 CONTRACTS

There were no general contracts among the owner, the general contractor, and subcontractors and no contracts related to the agreement to employ the lean construction.

The owner and general contractor understood the project goal to renovate the factory to a college medical center; however, they did not know initially what to do at the start of the project.

4.6.3 Feedback from Interviews

4.6.3.1 GENERAL CONTRACTOR INTERVIEWS

Progress is dependent on the design company's capability to support construction. The superintendent noted that there were no completed drawings from the architectural engineer (AE). The project often stopped because there were no drawings for the tasks. Providing a small number of drawings is the current trend of architectural design.

The superintendent liked lean construction. However, for the success of lean construction, whole submittals including information and drawings of the project have to be provided. The owner and the general contractor need to know what they have to do before the project starts.

The superintendent believed that lean construction should create good involvement and cooperation of the owner, architect and builder. However, if one hesitates to participate, lean construction fails.

He had many questions related to lean concepts and principles. He thought that the manufacturing and construction industry were fundamentally quite different and that the concepts or theories in manufacturing could not be applied to the construction industry. This opinion was similar to the superintendent's opinion in case study E.

The unions were quite good at working together. They knew what they had to do even though problems were not yet identified. This union situation totally contradicted case study E. This difference is due to regionalism. The northern U.S. has stronger unions than the southern U.S.

Lean construction emphasizes thinking ahead. It also requires promises from the workforce. If any problems occur, the superintendent should be notified immediately.

The superintendent felt that lean ideas seemed to be all about planning. The subcontractors themselves liked to plan. Planning and coordinating improves certainty and reliability, which motivates the workforce. When the subcontractors on the project learn all about working the schedule progress, uncertainty should decrease.

While the superintendent managed the project, he never gave the subcontractors a new form before they understood and were familiar with the form and process. He gave the lean planning system forms to them and taught them how to complete them. He did not miss the opportunity to tell the subcontractors why these things helped. Later he explained more about lean construction. He believed that people naturally resist changes. If he told the subcontractors that he would apply a new system in the beginning, they would hardly accommodate themselves to lean construction.

Two project engineers (A and B) were interviewed on the site visit.

Project engineer A was hired from another company, and this project was his first lean project at this company. He took an internal company training class before he was assigned to this project site and still confused about the concepts and principles; however, he had a positive attitude. He believed lean construction would improve project field productivity and workforce performance.

Project engineer B took two days of classes from the LCI. He said that lean construction helped everyone to know what was going on and to share all the information. The lean meeting was effective and it improved coordination and communication among project participants. Lean required lots of paper work and was time consuming, so an extra person has to be assigned to handle only lean things. If possible, software should be developed to facilitate the process.

The mechanical engineering project engineer's previous project employed lean construction, so he was, to some extent, familiar with lean construction.

He felt that the project had too many 'Requests for Information (RFI)' that were not answered quickly. There were also too many changes in the drawings. There were six addendums over three months.

The owner's representatives were all new and this was their first job. Thus, they were sensitive to the project cost. Whenever there were options to be determined by the owner, representatives in previous projects chose the best option while representatives in this project chose the cheapest one. They emphasized only saving money and time.

The bi-weekly work planner provided better prediction and adjustment of the work planned for the week or next week.

This project, to a large extent, depended upon the superintendent's experience, intuition and common sense. He was smart to manage the whole project, but if he had moved or transferred to another project, it was uncertain who could handle the jobs.

The MEPE was employed by an electrical company before he moved to this construction company. At the previous company, he had already used three-week planning for project controls. The LCI seemed to combine the good tools he already had used in the construction industry and made a work package for better management and a well- run job.

If lean construction is properly applied to the project, the subcontractors absolutely can improve productivity and save money. They can anticipate and experience much smoother work flow. They can also eliminate surprises caused from unanticipated problems. He indicated how important it was to make the workforce think ahead. Lean construction needs long-term planning to be well-adapted in the construction industry.

The MEPE thought there were some negative aspects to lean construction. For example, he thought it is difficult to make subcontractors understand lean concepts and principles and that extra time is needed for training and more meetings for coordination.

Lean construction is initially difficult to understand, but he stressed the importance of enduring hardships that lead to higher achievements. He also thought a contractual agreement improves lean implementation.

4.6.3.2 SUBCONTRACTOR INTERVIEWS

The mechanical foreman's company was strongly connected to the general contractor. Several superintendents and foremen in his company were working on lean construction. It was the first lean project for the foreman.

The project had many problems not related to lean. Concerns were there, but adequate reactions to them did not occur. There were many unanswered questions from the AE and the owner.

He had taken two training courses from the LCI. The lean meeting seemed to be effective and encouraged involvement. With the lean planning systems, more detailed planning and well-facilitated organization could be obtained.

He did note that lean practices required more paper work and that it was too oriented to computer work.

The electrical foreman said that the superintendent implemented lean construction and made the overall job easier. To be successful in lean implementation, a qualified person has to be assigned to the project and perform the implementation. In his point of view, the superintendent on this project was adequately assigned.

The project did not employ JIT delivery, but materials were usually delivered three days ahead.

The electrical foreman did not have any lean training.

The general contractor encouraged every foreman to attend three major meetings a week; the subcontractor meeting, construction meeting, and lean meeting. The lean meeting was similar to a productivity meeting.

Documentation in lean reminded participants of what must be done. Lean construction seems to provide better job coordination and planning. However, lean ideas are based on everyone's participation. If that is not achieved, it will not work.

The drywall foreman was not a union member. He did not have any lean training, but lean construction, especially lean planning systems relative to the schedule, looked good and effective.

The benefits of lean construction seemed to be coordination and good relationship between subcontractors. Friendship between subcontractors was above average compared to other previous projects.

The weakness of lean construction here was that there was no requirement to force all trades to be involved in lean implementation. A contract agreement could possibly solve this problem.

4.6.4 PPC and Root Causes of Failure

The PPC average on this project was 47%, which was the lowest score of all case studies. The PPC chart in Figure 4.6 indicated the average PPC was based on all subcontractors' reporting. The lowest PPC average seemed to be due to the lack of design information.

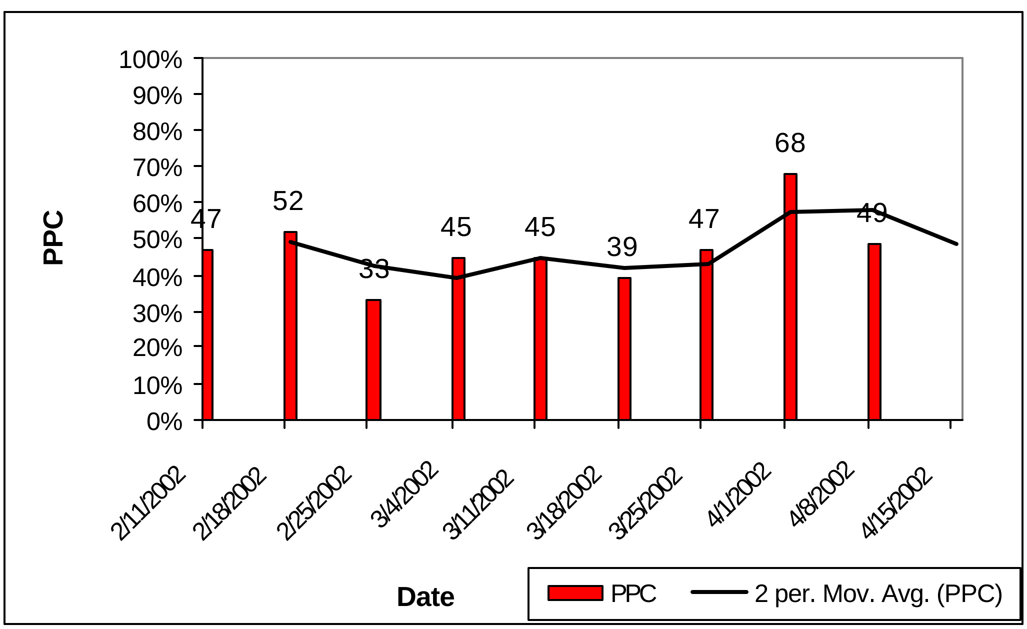

Figure 4.6. Percent Plan Complete (PPC) – Case F

This project did not analyze the root causes of failure to complete the planned work after calculating the PPC. In this case, the project could not obtain the benefits of constraints analysis such as thinking ahead, reducing waste of repetitive work and allocating buffers with workable backlog.

4.6.5 Strengths and Weaknesses

Strengths and weaknesses were identified by the project participants of case F. Lean construction promoted thinking ahead and checking for possible problems. It improved project field productivity and work performance. It made workflow much smoother by effectively facilitating the project, and eliminated surprises caused from unanticipated problems. Documentation, better job coordination, and detailed planning made the work easier and smoother given the difficult circumstances of this project.

The weaknesses of lean construction were paper work and time for training and meetings, the need for an extra person who mainly handled lean implementation, and the difficulty to force subcontractors to abide by lean concepts and its implementation. Lean implementation was too oriented to the computer and to the participation by all trades. Without a mandatory clause in the contract among the project participants, there was not any means of enforcement to make all trades get involved in lean implementation.

4.6.6 Questionnaire Responses

Referring to Table 4.15, the project showed high scores in job satisfaction and competitiveness of lean construction. Regarding competitiveness, the project superintendent scored low. He insisted that lean construction would not work if all submittals and information were not provided at the beginning of the project. The success of the project basically depended on human factors: good subcontractors and work crews and the relationships between them were major factors for success. The level of managerial time and the attention by management was almost the same as those projects not employing lean construction.

Table 4.15. Summary of Responses from the General Contractor - Case F

Question	Project Super-intendent	Project Engr (A)	Project Engr (B)	M.E.P.E	AVG	Remark
Managerial Time & Attention	4	4	2	4	3.5	Low is better
Job Satisfaction	4	Not Response	4	4	4	High is better
Turnover & Absenteeism	3	Not Response	Not Response	Not Response	3	Low is better
Competitiveness	2	5	5	4	4	High is better

* 1: much less or much worse, 3: about the same, 5: much more or much better

Table 4.16 summarized the responses of the subcontractors' foremen. It showed improvement of planning and coordination, involvement and commitment, job satisfaction, resource availability, working conditions, and work assignments. Due to design problems, the fire-fighting caused from unexpected and urgent problems was somewhat more than that of other projects.

The responses shown in Table 4.16 indicated that the overall project was effectively performed and managed. However, it is doubtful whether this good assessment was due to lean implementation.

Table 4.16. Summary of Responses from the Subcontractors - Case F

Question	Electrical Foreman	Plumbing Foreman	Drywall Foreman	AVG	Remark
Planning & Coordination	4	4	3	3.7	High is better
Involvement & Commitment	4	4	4	4	High is better
Fire-fighting	5	4	3	4	Low is better
Productivity	4	3	4	3.7	High is better
Unplanned OT	2	3	3	2.7	Low is better
Job Satisfaction	5	4	4	4.3	High is better
Rework	4	2	4	3.3	Low is better
Resource Availability	5	3	4	4	High is better
Working Conditions	5	4	4	4.3	High is better
Wasted Time	2	3	4	3	Low is better
Work Assignments	5	4	4	4.3	High is better

* 1: much less or much worse, 3: about the same, 5: much more or much better

4.7 CASE STUDY G

This case study focused on a general contractor and major key subcontractors who were involved in the construction of a new university dental school. Interviews were conducted with project teams from the general contractor and two major subcontractor organizations. The project's weekly planning meeting, which was attended by the general contractor's project manager, superintendent and lean facilitator, and project managers, superintendents or foremen from all three subcontractors, was observed.

4.7.1 Project Description

The project was a new university dental school project that was to be a reinforced concrete building with a total of 126,000 square feet comprised of three stories and a basement. The project was located in Wisconsin. When visiting the project site, the researcher interviewed the project manager and superintendent from the general contractor and two subcontractors (the electrical superintendent, and the drywall and insulation foreman). The construction contract was a Cost Plus Fixed Fee/Guaranteed Maximum Price for approximately $20M and duration of 18 months. The worker's status was union. The project had approximately one month left prior to being completed at the time of the site visit. Interviews had to be conducted quickly due to the tight schedule.

4.7.2 Results

The results were based on the observations, the course packages of the company, and interviews with the project participants.

4.7.2.1 PROJECT PLANNING SYSTEMS AND PROCESS

This project employed master scheduling with CPM, phase scheduling, lookahead planning with workable backlog, and weekly work planning. The project manager was not familiar with JIT delivery. The project performance was fundamentally oriented to the CPM to meet the owner's requirements and time schedule.

The weekly lean meeting was held every Thursday at 10:00 a.m. and took 90 minutes. At the beginning of the project, the meeting generally took 40 minutes to one hour, but the meeting was lengthening at the end of the project. The meeting discussed each subcontractor's weekly work in detail.

This project referred to the weekly work plan meeting as the last planner session. The project manager, superintendent and lean facilitator attended the meeting. The superintendent was in charge of the meeting. The facilitator showed each lean planning system on a screen according to the meeting procedure. She updated new data for the six-week lookahead schedule, WWP, and calculated PPC directly in her computer while the meeting was conducted.

The last planner session flow was as follows:

First, review the PPC from the current week's work. Second, develop the six-week lookahead schedule. Add items not completed from the current week. Add in any activities planned for the coming week by subcontractors. Review every line item of constraints. Modify items as needed and add items that are uncovered as prerequisite work.

Third, develop the weekly work plan for the next week. Magnify activities as necessary. Identify make ready needs. Identify the workable backlog for any work from the six-week lookahead schedule with no constraints and other work as identified by the participants.

All subcontractors attended the last planner session, and they related to the superintendent their week's performance and plans for the next week. At that time, communication occurred between the staff of general contractor and subcontractors and among the subcontractors. Then, all project participants modified and confirmed their schedule. If there was any subcontractor who did not attend the meeting, the staff called him and made him submit his plan in documentation.

A major difference of this project compared to other case study projects was that subcontractors did not prepare nor submit any lean planning forms prior to or at the last planner session. Some subcontractors prepared their plans and schedule prior to attending the meeting just for their own benefit, but some did not prepare anything. They attended the meeting and thought about their work sequence and tasks.

4.7.2.2 ORGANIZATION

The company strongly supported employing lean construction. All projects of this company were deployed under lean construction.

The owner knew that the general contractor employed lean construction. At the beginning of this project, when the general contractor insisted that the project would use lean systems, the owner was skeptical about the benefits. However, the owner was currently impressed with lean construction and was extremely cooperative.

Communication and coordination between the general contractors and subcontractors were significantly improved on this project. Foremen of the subcontractors said that the relationships among subcontractors were such that they had never experienced on other jobs. The meeting length was currently getting longer, but most participants thought that the meeting time was beneficial.

The general contractor provided a presentation on lean construction to the subcontractors before starting the project. After that, whenever a new subcontractor joined the project, the general contractor provided another lean presentation.

4.7.2.3 ATTITUDES

The project manager and superintendent employed lean construction well. They said that all employees of their company thought that it was natural to employ lean construction for their project management. They were all positive towards lean construction and had enthusiasm to improve lean implementation.

The subcontractors also had positive attitudes toward lean construction. Most subcontractors showed good involvement in planning at the lean meetings and commitment to implementing lean construction. However, some subcontractors lacked enthusiasm and commitment. As mentioned before, some did not develop their plans for the lookahead schedule and WWP. Most did not consider why they did not complete their planned work.

The owner's involvement was effective in that the designer had been preparing plans and specifications a year and a half. Even though there were many addendums and changes, full information and drawings were provided at the beginning of the project.

4.7.2.4 CONTRACTS

Contracts were made between the owner and general contractor, and the general contractor and subcontractors. These contracts required the implementation of lean construction. The project manager said that all construction projects of this company required contracts requesting the employment of lean construction. Subcontractors had to include the clause that they would employ lean construction in their proposal for the project.

4.7.3 Feedback from interviews

4.7.3.1 General Contractor Interviews

The project manager took three training sessions related to lean construction. He agreed that the designer's involvement was an important factor to improve lean construction, but also commented that the owner had to provide some incentives to the designer to encourage their involvement.

He found that the benefits of lean construction were that there were no arguments regarding sequence of work activities, the superintendent could manage the work but not the schedule, helpful communication occurred, and all participants could plan together before starting any work.

The project manager found that for this project the barrier of lean construction was tracking the plans. It was not easy to connect new tasks with previous tasks or to track a task from the lookahead schedule to WWP. He found that at first the owner was skeptical in employing lean construction, but currently the owner was impressed about lean and now preferred to employ lean construction for new projects.

He insisted that the long meeting length was unavoidable at the current stage of the job to maintain high productivity and performance. More communication and coordination made the meeting length longer, but was useful.

The facilitator took a two-day lean seminar from the LCI. She thought that lean construction made the job easier for the superintendent to track and focus on tasks. She had tried to gather plans prior to the lean meeting, so she asked the subcontractors to e-mail her the lean planning forms. She got nothing from the subcontractor foremen because they could not operate a computer and did not know how to send e-mail. She believed that for more effective meetings, the subcontractors had to prepare their plans before the meetings and submit them to the superintendent.

4.7.3.2 SUBCONTRACTORS INTERVIEWS

The superintendent of the electrical subcontractor commented that lean construction was beneficial even though it required more paper work.

The drywall foreman believed that lean construction was good for information sharing, and improved working relationships among project participants. He said that communication among subcontractors was a major benefit to implement lean construction.

The electrical superintendent and drywall foreman believed that this project could save two months due to the effectiveness of the lean meetings. Both commented that the lean meeting was significantly effective to project management.

They were dissatisfied with the tight scheduling required for the project. The project was based on the CPM to meet the owner's requirements and due dates. They understood it, but the time frame appeared to be unfeasible.

4.7.4 PPC and Root Causes of Failure

The meeting facilitator updated the PPC results, printed out the results for the week, and distributed the results to all of the project participants at the next week's meeting. This project kept PPC results graphically as illustrated in Figure 4.7. This was useful and effective to review and check reliability and consistency of performance. Compared to other project PPC charts, this seemed to be more beneficial to manage the project. This graph shows a goal line at 83%, and the current PPC average of this project was 75%. The project manager had anticipated less fluctuation of PPC results, but this PPC chart shows that the actual results changed significantly from week to week. Fortunately, the gap of the PPC results was getting narrower at the end stage of this project.

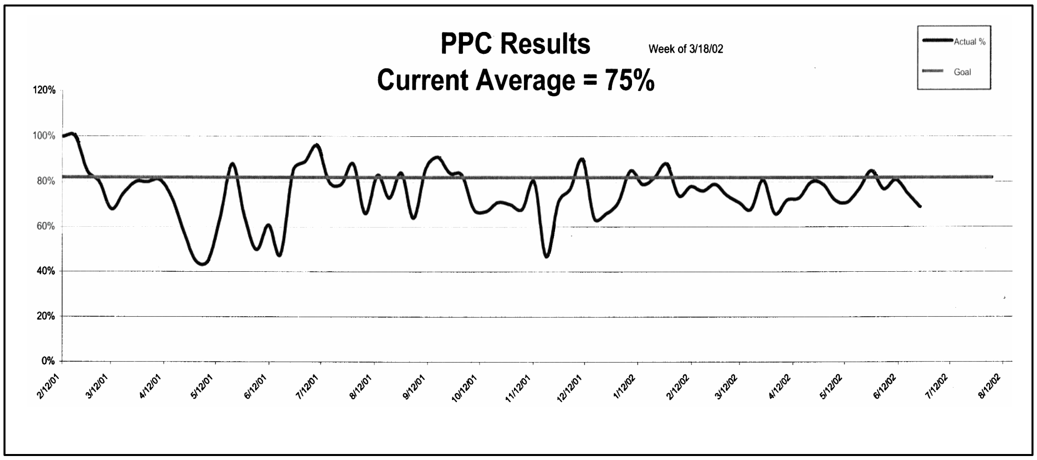

Figure 4.7. Percent Plan Complete (PPC) – Case G

Data for root causes of failure to complete work were not obtained at this project. The facilitator said that most problems on this project were caused from the size of the project site. The project had a total of 126,000 square feet and 410 rooms. Also, there was an average of 160 workers on the site. The subcontractors stocked their materials in the building area, so space was consumed by materials and subcontractor manpower. Thus, subcontractors claimed access problems to their work place.

The other problem in this project was that there was a lack of ability to make the owner and subcontractors implement corrective action against the root causes identified.

4.7.5 Strengths and Weaknesses

Strengths and weaknesses were identified by the project participants of case G. Lean construction helped the project to strengthen business relationships and improve cooperation and communication on the job site.

The strengths of lean construction observed from the interviews on this project are summarized below:

- All project participants planned together prior to starting work.
- Communication and coordination among the project participants was greatly improved.
- There was little disagreement due to full communication, discussion and conflict-solving.
- Subcontractors were cooperative and shared tools with different trades.
- More detailed planning was obtained.
- Lean working conditions made the work enjoyable.
- Lean construction made the job easier for the project manager and superintendent to manage the project. Secondly, it was easy to track and focus on tasks.

The weaknesses were as follows:

- Weekly meeting length was getting longer according to work details. Thereby, the meeting could not be efficient at the participants' involvement.
- It was not easy to track tasks from each of the planning forms.
- It was not easy for people to understand lean construction.
- It was difficult to obtain qualified subcontractors.
- The general contractor had to check whether subcontractors reacted to root causes of failure identified at the weekly lean meeting.
- Lean implementation was computer-based, but most foremen were not familiar with computer operation.

The requirements for lean implementation emphasized by the interviewees were as follows:

- The weekly lean meeting has to be balanced properly. Too long of a meeting makes subcontractors bored and contributes to the lack of involvement.
- Subcontractors should prepare their plans early in the week and submit their schedule to the superintendent to be modified prior to the weekly meeting.
- Workable backlog has to be effectively identified and not be just for show.

4.7.6 Questionnaire Responses

This project was well-organized and all project participants had positive attitudes toward implementing lean construction. The general contractor implemented lean planning systems quite properly, and the subcontractors followed directions. The staff of the general contractor was confident in employing lean construction as their project management method.

A major difference compared with other projects was that a facilitator was assigned for this project to update the project weekly performance and to make the lean planning forms immediately at the weekly lean meetings. This job is generally a role of project engineers on other project sites, thus causing the project engineers to indicate that they had more managerial time to manage the project. They claimed that an extra person to handle the lean process was needed for each project. The facilitator could solve this problem.

Just-In-Time delivery was strongly recommended for the project. A major problem was accessibility to the work place due to material storage and overcrowding. To prevent an overcrowded work place, the general contractor had to spend more time to provide logistics for effective workflow and work sequences.

Referring to Table 4.17, the responses from the subcontractors were mostly the same as in the responses of other projects. The project showed high scores in job satisfaction and competitiveness of lean construction. The level of managerial time and attention of the management was almost the same as those projects not employing lean construction.

Table 4.17. Summary of Responses from the General Contractor - Case G

Question	Project Manager	Project Superintendent	AVG	Remark
Managerial Time & Attention	3	4	3.5	Low is better
Job Satisfaction	4	5	4.5	High is better
Turnover & Absenteeism	3	3	3	Low is better
Competitiveness	4	4	4	High is better

* 1: much less or much worse, 3: about the same, 5: much more or much better

Table 4.18 summarizes the responses of the subcontractors' foremen. It shows improvements of planning and coordination, involvement and commitment, productivity, job satisfaction, less wasted time and better work assignments. However, both subcontractors indicated that working conditions were worse compared to other projects. Again, this was due to the accessibility of the work place. Resource availability was a problem for the electrical subcontractor. The electrical superintendent claimed that information from the designer was provided too late. The drywall foreman claimed that there were many reworks due to the complexity and specialties of the project.

Table 4.18. Summary of Responses from the Subcontractors - Case Study G

Question	Electrical Superintendent	Drywall Foreman	AVG	Remark
Planning & Coordination	4	5	4.5	High is better
Involvement & Commitment	4	5	4.5	High is better
Fire-fighting	3	4	3.5	Low is better
Productivity	4	5	4.5	High is better
Unplanned OT	3	3	3	Low is better
Job Satisfaction	4	4	4	High is better
Rework	2	5	3.5	Low is better
Resource Availability	2	5	3.5	High is better
Working Conditions	2	2	2	High is better
Wasted Time	3	2	2.5	Low is better
Work Assignments	3	5	4	High is better

* 1: much less or much worse, 3: about the same, 5: much more or much better

4.8 CASE STUDY H

While carrying out case study G, the researcher interviewed four project managers of the company at the home office. They responded to the questionnaires and assessed their subcontractors. Three out of four project managers provided a brief description of each project and of lean aspects employed in each project.

4.8.1 Project H-1

The project scope was interior hospital remodeling. The approximate construction cost of this project was $3M, and its duration was 10 months. Labor was all union.

The project employed master scheduling, lookahead and WWP. The weekly lean meeting was held once a week with the owner, architecture, subcontractors, general contractor, and a facilitator. It usually took one hour. Training for the subcontractors was provided at the time of introduction to the project. The project did not implement phase scheduling and root causes analysis.

All participants' attitudes toward lean construction were absolutely positive. The project manager believed that lean construction would be accepted as one of the critical success issues in the construction industry. She found that lean construction had the benefits of more open communication, more detailed planning, and a better work sequence. She also found that keeping the involvement of subcontractors was an opportunity for improvement. The project manager commented that the key factors for successful lean implementation were planning, involvement and commitment, and coordination and communication.

4.8.2 Project H-2

The project scope included construction of a 250-bed maximum security housing unit, a 60-bed mental health unit, and a 60-bed segregation unit at a women's prison. The construction cost of this project was $17M and duration was 14 months. Labor was both union and open-shop.

The general contractor applied phase scheduling, lookahead planning and WWP to the project. The project had a weekly last planner meeting and a schedule update meeting once a month. The last planner meeting usually took 90 minutes. The project manager found that the last planner meeting had the benefit of coordination of subcontractors, sequencing of ideas from subcontractors, a cooperative jobsite, self regulating, schedule acceleration, budget gains, and progress documentation. However, it was difficult to get participation by the lower tier subcontractors. CPM was used to monitor the overall schedule.

There was no owner and designer participation. The attitude of the general contractor and subcontractors were very positive, and 99% of the subcontractors showed excellent participation.

The benefits of lean construction came from the participation of everyone in the scheduling process as well as the organization on site. The biggest change was the participation of the subcontractors in the weekly planning as well as the overall schedule.

The project manager indicated that the key factors for successful lean implementation were planning, foremen abilities, and personal work experience. He also emphasized involvement, commitment, coordination, and communication.

4.8.3 Project H-3

The project was a 475,000 square foot hospital expansion. The approximate construction cost was $125M and duration was 40 months. Labor was all union.

The project employed master scheduling, lookahead schedule, WWP and JIT delivery. The lean meeting was held one morning each week. The project manager, superintendent, owner, engineers, architect and a facilitator attended the meeting. The length of the meeting was usually 90 minutes. This project also used CPM together with lean systems.

The general contractor provided a handout guide to the subcontractors for lean implementation.

The attitudes of the owner and general contractor were receptive and advocated the use of lean. However, the designer was somewhat resistant, and some subcontractors were negative towards lean construction.

The project manager found that the benefits of lean construction were awareness of the owner's work and facilitation of workflow.

He commented that the most important key factor for successful lean implementation was the change of organizational culture including the bureaucracy and power culture. Other key factors were almost the same as in project H-2.

4.8.4 Strengths and Weaknesses

Strengths and weaknesses were obtained from the four project managers. The benefits of lean construction identified by the project managers were as follows:

- Better coordination
- Open-communication
- Better workflow management

- Forward looking at problems prior to the start of the work
- Well-formatted meetings
- Knowledge about what participants did
- Credibility to the owner

The biggest barrier to lean construction related to design involvement. A project manager recommended that the general contractors should try to develop owner and designer participation. For instance, the general contractor checked the progress of architect at the stage of pre-construction. The project manager had an eight-month design and development period and checked on the progress every month to discuss problems found.

The opportunities for improvement observed from the project managers were as follows:

- Tracking difficulty between each of the lean planning forms
- Constraints analysis
- More feasible planning needed
- Well-balanced meeting and effective meeting length
- Weekly lean meeting on Friday

4.8.5 Questionnaire Responses

The project managers responded to the short questionnaires and also evaluated their subcontractors. Project description and lean aspects were not obtained from project H-4, but the project manager of the project responded to the questionnaires and assessed his subcontractors. Table 4.19 shows the responses from the four project managers.

Job satisfaction and competitiveness were slightly higher than the average. Through the interviews with the project managers, the researcher found that the project managers of the first two projects were highly interested in lean implementation, while the latter two project managers were less eager to implement lean construction. The responses in Table 4.19 seem to reflect their enthusiasm toward lean implementation.

Table 4.19. Responses from the Project Managers – Case H

Question	Project Manager (H-1)	Project Manager (H-2)	Project Manager (H-3)	Project Manager (H-4)	AVG	Remark
Managerial Time & Attention	3	2	3	3	2.75	Low is better
Job Satisfaction	4	4	3	3	3.5	High is better
Turnover & Absenteeism	2	3	3	3	2.75	Low is better
Competitiveness	4	4	4	3	3.75	High is better

* 1: much less or much worse, 3: about the same, 5: much more or much better

The project managers evaluated their subcontractors. Table 4.20 summarizes the responses by the project managers. There was improvement of the overall subcontractors' performance: planning and coordination, involvement and commitment, job satisfaction, and work assignments. The project managers claimed that most major subcontractors liked lean construction but that minor subcontractors disliked lean construction.

Table 4.20. Subcontractors Evaluation by the Project Managers – Case H

Question	Project Manager (H-1)	Project Manager (H-2)	Project Manager (H-3)	Project Manager (H-4)	AVG	Remark
Planning & Coordination	5	4	4	4	4.25	High is better
Involvement & Commitment	4	4	4	4	4	High is better
Fire-fighting	2	1	3	2	2	Low is better
Productivity	4	4	4	3	3.75	High is better
Unplanned OT	2	1	3	2	2	Low is better
Job Satisfaction	4	4	3	4	3.75	High is better
Rework	2	2	3	3	2.5	Low is better
Resource Availability	4	3	4	3	3.5	High is better
Working Conditions	4	4	4	2	3.5	High is better
Wasted Time	2	2	3	3	2.5	Low is better
Work Assignments	4	4	4	4	4	High is better

* 1: much less or much worse, 3: about the same, 5: much more or much better

Each case study has been summarized in this chapter. Lean concepts and systems used on the project, observations and interview feedback from the project team of the general contractor and subcontractors, and the results of the short questionnaire were also included in the chapter. In Chapter 5, research findings for the assessment of lean construction will be discussed.

Chapter 5: Research Findings, Analysis and Discussion for the Assessment of Lean Construction

Through case studies, this dissertation attempts to determine to what extent lean construction has been adapted by the construction industry and to assess how properly lean construction has been implemented in construction. To measure these factors, the study compares and analyzes case studies while focusing on the following. (1) To implement lean construction successfully, lean planning systems are essential tools; however, the success or failure of lean implementation is dependent upon the human resources working on the lean construction sites, as discussed in Chapter 3. (2) The efficiency of human resources can be improved by company project strategies including contracts, company policies and Human Resource Management (HRM) policy.

A comparison of the case studies is provided in this chapter and summarized in Table 19. These findings are based on interviews with project participants and observations from the projects. Categories and descriptions used in this comparison were described in the literature review of lean construction principles. This chapter also summarizes the responses to the short questionnaire obtained from project participants based on each case study project. Finally, this chapter analyzes the results of all the case studies.

5.1 COMPARISON OF CASE STUDIES

Most of the selected project sites indicated that they were in the experimental stage of implementing lean construction. The projects implemented the major lean planning systems such as master scheduling, last planner and weekly meetings, but were less focused on understanding lean concepts and principles. This took less time and was more comfortable for project participants at real construction sites to accept lean systems rather than spending time to understand the theories. Subcontractors interviewed at the projects were not familiar with the theoretical lean ideas, but were interested in using the planning systems.

Based on Table 5.1, case A successfully implemented most lean concepts in its project and properly implemented them. Cases B and G also utilized most of these concepts as in case A, but were overall less effective. However, the researcher found that these projects were also good lean implementation sites especially compared to other cases in general. Case C obtained high score on its lean implementation, but focused on narrow lean application because it was a pilot project to evaluate the last planner. Observations and interviews from case C showed that this project successfully implemented the last planner and created a good work environment to reinforce organization and improve the attitudes of project participants. Cases D and E were the poorest lean implementation projects. Their major problem was caused from the lack of the subcontractors' participation in lean implementation. The general contractor in case D indicated that it was too small and simple of a project to employ lean construction. The PPC of case D was high, but was due to simple tasks. In case E, lean construction was applied too late and the workers were less cooperative union members. The PPC of case F was the poorest compared to other cases because there was a lack of project definition and insufficient design and information.

Table 5.1. Comparison of Case Studies

Category	Description		Case A	Case B	Case C	Case D	Case E	Case F	Case G
Project Planning Systems	Master Scheduling		O	A	X	X	A	A	A
	Last Planner	Lookahead	O	O	O	A	A	A	O
		WWP	O	O	O	A	O	O	O
		Workable Backlog	O	O	O	X	X	X	A
		PPC (%)	85%	77%	80%	76%	59%	47%	75%
	Weekly Meeting		O	O	O	A	A	A	O
	JIT Delivery		O	X	X	X	O	X	X
Organization	Organizational Support		O	A	A	X	A	A	O
	Communication	GC + Subs	O	A	O	A	O	A	O
		Subs	O	O	O	X	A	O	O
	Coordination	GC + Subs	O	A	A	A	A	O	O
		Subs	O	O	O	X	X	A	O
	Training	GC	O	O	O	O	O	O	O
		Subs	O	A	O	X	X	X	O
Attitudes	Involvement	GC	O	O	O	A	O	O	O
		Subs	O	A	O	X	A	A	O
	Commitment	GC	O	O	O	A	O	O	O
		Subs	O	A	A	X	X	A	A
	Enthusiasm	GC	O	A	O	X	A	A	O
		Subs	O	A	O	X	X	A	A
	Open-mindedness	GC	O	A	O	A	O	O	O
		Subs	O	A	O	X	X	A	O
	Motivation	GC	O	O	O	X	X	A	O
		Subs	O	O	O	X	X	A	O
Contractual Restraints	Owner + GC		O	X	X	X	X	X	O
	GC + Subs		O	X	X	X	X	X	O

* Utilized: O, Not effectively utilized: A, Not utilized: X

** Criteria for evaluation

- Master schedule
  - O: Master scheduling mainly used
  - A : Master scheduling used, but CPM mainly used
  - X: No master scheduling, and CPM mainly used

- Last Planner
  - O: Last planner effectively used
    - No arguments and conflicts indicated by interviewees
    - Satisfied by interviewees
  - A: Last planner used not effectively
    - Arguments indicated by interviewees
    - Problems identified during site investigation
    - Not fulfilled LCI's requirement
  - X: Not used
- Weekly Meeting
  - O: Lean meeting managed effectively
    - No arguments and conflicts indicated by interviewees
    - Satisfied by interviewees
  - A: Lean meeting managed not effectively
    - Arguments indicated by interviewees
    - Problems identified during site investigation
    - Not fulfilled LCI's requirement
  - X: No meeting held
- JIT Delivery, Training & Contractual Restraints
  - O: Utilized (provided) on sites
  - X: Not utilized (provided) on sites
- Organization & Attitudes
  - O: Effectively promoted
    - No arguments and conflicts indicated by interviewees
    - Satisfied by interviewees
  - A: Not effectively promoted
    - Arguments indicated by interviewees
    - Problems identified during site investigation
  - X: Not promoted

5.1.1 Project Planning Systems

Among the project planning systems, lookahead planning, the weekly work plan, PPC and the weekly lean meeting were implemented at all the project sites. These planning systems played an important role in terms of getting the commitment of different subcontractors. The lookahead schedule was used in six-week lookahead and two-weak lookahead. The six-week lookahead schedule was used on most project sites, but the two-week lookahead schedule was used on three projects, cases A, B and C. Most projects, therefore, experienced the benefits of the above-mentioned planning systems. The participants assessed them as the most valuable systems for successful lean construction.

However, employment of master scheduling and workable backlog showed opportunity for the improvement. As shown in Table 5.1, master scheduling was not used in cases C or D, and was not used as a fundamental scheduling at most projects. Project superintendents preferred CPM, a traditional schedule method instead of master scheduling. CPM has not been totally eliminated from current lean construction practice and was used in parallel with lean planning systems. Most projects used the CPM to monitor the overall schedule and to meet the owner's requirements.

The LCI insists that obtaining the workable backlog in the lookahead planning stage is one of the important factors that determines the success or failure of a project. Even though cases D, E, and F held weekly meetings and performed the lookahead schedule, they did not endeavor to maintain the workable backlog making work ready by screening, pulling, and first-run study. In these instances, the benefits and effectiveness of lookahead schedule decreased.

In case G, the project employed the workable backlog, but it was not effectively utilized to provide work assignments based on quality criteria. It seemed to be considered just as a process to be shown in planning meetings.

After calculating the PPC of the week, root causes of failure to complete planned work are identified by project participants. Then, consistent analysis and action on reasons for failure to complete work have to be performed to prevent future repetitive failures. Most projects, unfortunately, had identified the root causes for failure, but failed to analyze and implement corrective action. The subcontractors and the general contractors provided no feedback regarding corrective steps to reduce planning failures.

Most projects tried to finish their lean meetings within one hour. However, the lean meeting at case G usually took one and a half hours. Long meeting length decreased the subcontractors' participation and commitment. Case G needed to hold more effective and efficient meetings by balancing the meeting length and focusing on the major issues.

Just-In-Time (JIT) delivery is uncommon on construction sites in this study. While a successful case of JIT was observed in case study A, most subcontractors were against it. The subcontractors commented that at least three days or even a week was needed to obtain materials prior to the start of work if they had to employ JIT. Furthermore, project site layout must be reviewed to provide storage to prevent double handling after delivering materials. Case G had a serious accessibility problem due to the size of project site. Thus, JIT delivery was a recommendation.

5.1.2 Organization

5.1.2.1 ORGANIZATIONAL SUPPORT

Most projects lacked organizational support in the implementation of lean concepts, except for cases A and G. Involvement of the owner was important for successful lean implementation, but excessive participation reduced the overall effectiveness of project performance. The opposite extremes of results in project performance due to the extent of owner involvement can be compared between cases A and F. While the owner's positive support of case A increased the project's performance, the negative support of the owner in case F decreased the project participants' overall project performance.

Company-level support was needed to reinforce lean implementation. As observed in the interviews with project participants, the upper-level management in most companies was enthusiastic to apply lean construction to new projects, but little support was found for introducing this change in management. Generally no changes occurred in company policy, HRM policy, or contractual clauses. Among the case studies, case G had the strongest company-level support. This company made it policy to apply lean construction to all new projects.

5.1.2.2 COMMUNICATION AND COORDINATION

Communication and coordination are major factors that support lean implementation. All project participants indicated that a higher execution of coordination, cooperation and communication was developed under lean construction. All foremen agreed that the best benefit of lean construction was the improvement of the working relationship among the trades. At the weekly lean meeting, all subcontractors knew what they had to do and what other trades would be doing in that week. The trades could understand each other's workflow. A subcontractor would consider the other trades' needs, and vice versa. If there were unexpected problems, they could be approached by a problem-solving team. As can be seen in Table 5.1, overall results of communication and coordination among project participants showed improvement compared to projects not employing lean construction. Communication among subcontractors was dramatically increased on lean construction sites. However, in cases D and E, since the subcontractors did not have much interest in lean implementation, the coordination and communication were not effectively achieved. Some projects failed to create an open-communication environment between the general contractor and subcontractors. Since the general contractors in cases A, C and G had good communication and mutual coordination with the subcontractors, they could successfully implement lean. Conversely, the major cause of failure in communication between the general contractor and subcontractors in cases E and F was that the superintendents were still in the position of boss of the subcontractors and ordered them to follow directions.

5.1.2.3 TRAINING

Construction training focused on the lean tools that can improve productivity and performance, and minimally focused on the lean concepts and principles. The study found that most owner and general contractor project team members were aware of lean theoretically, but that subcontractors were rarely aware of lean. Subcontractor foremen in most case projects were not eager to learn lean concepts and principles. They just wanted to know how to use the forms of the Last Planner System, and how to effectively implement lean planning systems on a construction site.

As shown in Table 5.1, general contractors were able to learn lean principles and concepts through their company's training program. Most project engineers, when first assigned to a lean project site had already taken at least one training course. On the other hand, subcontractors had less of a chance to take any educational courses. Several subcontractors let their superintendents or foremen attend an LCI seminar that generally introduced the baseline of lean construction. Only two project sites provided official training sessions to the subcontractors. In case B, the general contractor did not provide any training sessions for the subcontractors, but it requested a subcontractor's foreman instead who had lean experience on a previous project to help the other subcontractors' foremen to implement lean planning systems and their forms. If it is too difficult to provide training to subcontractors due to the lack of time or money, the alternative used in project B can be substitute for a training session. The general contractor in case C suggested spending 20% of training time on lean theory and 80% on "how-to" to prevent early difficulties in establishing implementation details and forms. The general contractor in case G provided lean orientation to the subcontractors at the beginning of the project and also provided a lean orientation whenever a new subcontractor joined the project.

5.1.3 Attitudes

Project participants' attitudes toward lean construction were a sensitive factor for successful lean implementation. The study found that overall attitudes of general contractors toward lean construction were good; however, the study also found that attitudes of subcontractors were not as good.

5.1.3.1 GENERAL CONTRACTORS

Most general contractor project team members tried to implement lean construction on their sites because they knew the benefits of lean construction through internal training courses or external LCI sessions. This was most likely the reason why the attitudes of general contractors were less affected by utilization of organization and planning systems than the subcontractors.

Lean construction not only has practical lean planning systems, but also has many theoretical concepts and principles including facilitation of smooth workflow, JIT, perfection, the pull schedule and value stream. Several project managers and engineers, unfortunately, thought that lean was only beneficial as a tool which supports making more detailed planning and schedules. They said they could not find any new concepts in lean construction.

Several projects employed lean only because the encouragement of upper-level management. Thus, most general contractors had less enthusiasm to implement lean construction at the project level. In addition, those with a long history of traditional experience did not want to change their practices. Project managers wanted to complete the projects on schedule and on budget, but were not fully convinced of the success of the projects employing lean construction; hence, they gave the superintendents full responsibility for project management. The superintendents outwardly utilized lean construction, but still managed the project based on traditional management methods.

Motivation of general contractors was found to be different between cases A, B, C, and G as compared to D, E, and F, as shown in Table 5.1. This shows that the projects successfully utilizing lean planning systems and organization derive high motivation from the use of lean and vice versa.

5.1.3.2 SUBCONTRACTORS

The study showed that attitudes of subcontractors under good organization and utilization of project planning systems showed good indicators (e.g. cases A, B, C and G), while the attitudes of those involved in cases D, E and F showed bad indicators in involvement, commitment, enthusiasm, open-mindedness and motivation. This clearly explains that the best utilization of organization and project planning systems has a significant influence on the attitudes of subcontractors.

Interviews with subcontractors in each case showed that there were three reasons for the lack of involvement and commitment. The first reason was the lack of new subcontractors' involvement and commitment. New subcontractors assigned to the project at the middle of a construction phase had difficulties in implementing lean construction. They had to understand lean construction and learn everything in a short period of time while the project was underway. The second reason was the preferences of the project manager or superintendent who dominated the project.

When project managers strongly encouraged using lean and subcontractors followed the project managers, the subcontractors' involvement and commitment increased, plus they were more motivated. Subcontractors believed that they knew their work better than anyone else and that they could best facilitate and allocate their own labor and match materials and equipment to their effort under lean construction. Thus, they enjoyed making their schedules and plans by themselves. They also liked to communicate and discuss their work and problems together with the general contractors and the other trades to coordinate work assignments. They felt self-fulfillment, recognition by others, and achievement by doing the above activities. Of course, there were many subcontractor foremen who did not care about lean systems and followed the orders of the superintendent, but the foremen in cases A, B, and G decided to apply lean planning systems to future projects for their own benefits, even though the general contractor might not employ lean construction.

Conversely, when project managers did not care whether superintendents used lean and the superintendents did not want to use new practices and persisted in their old management styles, then the subcontractors' attitudes were negatively affected. In that case, subcontractors had less authority to participate in decision-making for their own work and to prepare and self-manage their schedule and plan.

The third reason was that some subcontractors did not see the necessity of employing lean construction and did not try to understand lean construction. These problems were found in cases D and E, which hired union-subcontractors.

The more positive and active attitudes the project participants had, the better and more successful the lean implementation. After deciding to employ and implement lean construction, the general contractors need to inspire subcontractors' involvement and commitment.

5.1.4 Contractual Restraints

The enthusiasm and involvement of project participants to implement lean construction should be empowered by contractual relationships. As observed from the case studies, only cases A and G had contractual agreements to use lean among the owner, the general contractor, and the subcontractors. The contract required all participants to try to use the lean ideas and systems. Of course, there are many other factors driving the successful project, but one of the essential factors for lean success in case A, at least at the starting point of the project, was the contractual agreements. Without any mandatory clause in the contract among the project participants, there was no assurance that all trades would participate in lean implementation. The general contractor company of case G always required contracts specifying lean implementation. The staff of case G naturally accepted lean construction as a project management method.

5.1.5 Responses from the Project Participants

Table 5.2 summarizes the averaged responses of the general contractors and subcontractors for each study. These responses were based on the short questionnaires conducted at the time of each site visit.

Table 5.2. Questionnaire Responses from Project Participants

Category	Description	Case A	Case B	Case C	Case D	Case E	Case F	Case G	H 1 – H 4
Responses from the General Contractors	**Managerial Time & Attention**	3	3.5	X	2	3.4	3.5	3.5	2.8
	Job Satisfaction#	5	4.5	X	4.5	2.7	4	4.5	3.5
	Turnover & Absenteeism	2	2.3	X	2	2	3	3	2.8
	Competitiveness#	4	4	X	4	4	4	4	3.8
Responses from the Sub-contractors	**Planning & Coordination#**	4.7	3.7	4.4	4	3.4	3.7	4.5	4.2
	Involvement & Commitment#	5	4	X	4	3	4	4.5	4
	Fire-fighting	1.7	2.7	2.5	3	3	4	3.5	2
	Productivity#	4.3	4.3	3.3	3	3	3.7	4.5	3.8
	Unplanned OT	1.3	1.3	1.6	2	3	2.7	3	2
	Job Satisfaction#	4.7	4	X	2	3.4	4.3	4	3.8
	Rework	X	X	X	4	3	3.3	3.5	2.5
	Resource Availability#	X	X	X	3	4	4	3.5	3.5
	Working Conditions#	X	X	X	3	3.7	4.3	2	3.5
	Wasted Time	X	X	X	2	2.7	3	2.5	2.5
	Work Assignments#	X	X	X	3	3.4	4.3	4	4

* 1: much less or much worse, 3: about the same, 5: much more or much better
Not answered: X

* Superscript #: High is better

5.1.5.1 RESPONSES FROM THE GENERAL CONTRACTORS

There were 21 project team members from the general contractors that participated including project managers, project engineers and superintendents.

There were no significant differences in scores found regarding managerial time and attention compared to other similar projects not employing lean construction. Case A scored managerial time as average because the project manager scored one and the project engineer scored five for this question. The reason seemed to be because of the various duties of each within their organization. Case D showed a good score to this question, but it seems to the researcher that it may be due to simple tasks. The additional projects H1, H2, H3 and H4 also indicated that managerial time required was near average.

All project participants had high job satisfaction on lean construction sites except case E, which scored the lowest. The general contractors in cases A, B and G had high job satisfaction and were motivated by lean. Case D also showed high job satisfaction, but this seemed to be because of the staff's knowledge of lean construction, not because of the work itself.

Turnover and absenteeism was slightly decreased under lean construction. However, it seemed that lean did not have a major influence on turnover and absenteeism.

Project team members also anticipated that the companies employing lean construction would be more competitive than companies not employing lean construction in the construction industry.

5.1.5.2 RESPONSES FROM THE SUBCONTRACTORS

There were 21 subcontractors who responded to the questions and four subcontractor evaluations were filled out by project managers. Subcontractors indicated that planning and coordination were greatly improved by lean. Cases A, C and G indicated significant improvement in planning and coordination. Even though case B utilized all aspects of lean and was assessed as a good lean implemented site, the planning and coordination score was lower than those of cases A, C and G. This was due to the lack of subcontractors' involvement in planning and coordination in the weekly lean meetings compared to cases A, C and G.

Lean caused improvement in involvement and commitment, less fire-fighting, improved productivity, and less unplanned over time as well.

Subcontractors generally said that they had greater job satisfaction on lean construction projects when compared to traditionally managed job. As can be seen in Table 5.2, there were significant differences in scores regarding job satisfaction among case studies however. Cases D and E scored that they had lower than average job satisfaction.

Case D scored lowest in rework, resource availability, working conditions, wasted time, and work assignments as reported by the subcontractors.

Case G also had problems with rework and working conditions. As mentioned before, the size of the project site was too small to prevent access difficulties, and design information was provided too late.

5.1.6 Root Causes of Failure

Figure 5.1 shows the average frequency of root causes of failure to complete planned work. The root cause analysis was obtained from only four out of ten projects: cases A, B, D and E The total effect was scaled to 100% to show the frequency of root causes for all 94 weeks of the four projects. The root causes were identified when PPC was calculated. Generally, each project had similar categories of root causes: make ready, manpower, schedule accuracy, material, coordination, rework, equipment, weather, design, and others. Others included unknown condition, overcrowding, contract, and client decision that were just identified on one or two projects. Except of the category of others, all other categories were at least identified on three projects. As can be seen, four major causes were identified from the study: make ready, manpower, material delivery, and schedule accuracy. Make ready and manpower were major root causes of failure. Failure to make ready and manpower had many causes for difficulties that prevent achieving planning work. The failures were due to the lack of schedule accuracy, incomplete pre-requisite work, design changes, lack of information, and ineffective use of the work backlog and constraints analysis. However, it was an unexpected result that make ready would have the highest frequency of root cause of failure due to effort devoted to planning work. It seemed to be required to develop more detailed and reliable workable backlog at the lookahead planning. It would be even greater on other projects that devoted much less time to short internal planning.

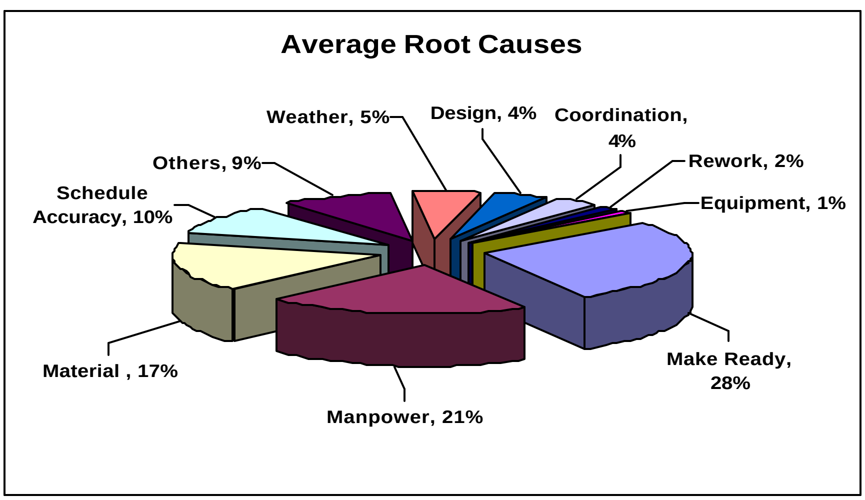

Figure 5.1. Average Root Causes

5.1.7 Summary

The researcher found that Table 5.1 and 5.2 were significantly matched in their results. The best-implemented lean projects showed high scores in the survey responses. The lowest scores were found among cases D, E and F. They were also considered the worst projects for implementing lean construction.

The most interesting comparison was in job satisfaction between the general contractors and subcontractors in case D. The results were opposite to one another and clearly showed how lean implementation was influenced by the subcontractors. The reason why the score was high in job satisfaction for the general contractor seemed to be that the project manager and project engineer had a strong lean background and knew the benefits of lean construction, so they were not seriously affected by the lack of effort by their subcontractors in utilizing lean planning systems and other factors. The subcontractors did not see the necessity of employing lean construction, so they were not enthusiastic to implement lean construction.

Comparing motivation in Table 5.1 and job satisfaction in Table 5.2 showed a similar trend. The projects that successfully improved motivation also improved job satisfaction for both general contractors and subcontractors.

Overall, the environment of case study A is highly recommended for benchmarking. The owner's active involvement, the project manager's enthusiasm, head office support, contractual agreements, the full implementation of all aspects of lean, and the motivated subcontractors' attitudes toward lean construction made the project successful in lean implementation. Cases B, C and G were also determined to be effective lean implementation sites. Case D was recognized as the worst site even though the general contractor staff had a strong lean background. Subcontractors were not interested in or motivated by lean construction on case D. Case E was better than case D, but still had problems in implementing lean construction. As mentioned before, the late application of lean construction and the use of union subcontractors were major obstacles to implementing lean construction. Case F was the most difficult to assess lean implementation because this project outwardly implemented lean construction properly and scored over the average for most questions. However the researcher doubts that these results were solely caused by lean implementation. The superintendent on this project had 47 years of work experience, so he effectively facilitated the subcontractors' tasks and labor management by effective sequencing of work activities. He knew how to control the subcontractors, and how to manage work flow. Subcontractors followed his directions regardless of lean implementation.

All project participants were dissatisfied with design involvement in lean construction. There were many design changes and design omissions and errors. There were also many requests for information. Without commitment of the designer, this dissatisfaction could not be resolved.

Coordination under the responsibility of the general contractors and commitment from the subcontractors are critical to successful implementation of lean construction principles.

5.2 PERCEPTIVE STRENGTHS AND WEAKNESSES OF LEAN CONSTRUCTION

The following section discusses the benefits and barriers of implementing lean construction. Requirements to implement lean construction are discussed as well. Strengths and weaknesses of lean construction that are discussed in this section were mainly indicated by the project participants of all case studies.

5.2.1 Perceptive Strengths

1. The most significant benefit of lean implementation was communication and cooperation among the project participants. The subcontractors' involvement and commitment in planning, and the participants' sharing of comments and goals at the meeting made it possible to know when and what each participant would be doing.
2. Lean construction caused little fluctuation in manpower. The lean planning systems also provided a short checklist of things which can be easily missed.
3. Lean construction had the benefit of forcing good documentation, and could also provide historical data to qualify subcontractors for future lean projects and furthermore provided fast and easy feedback to review the reasons to failure.
4. Prediction for upcoming work and ease of driving the whole project were important factors in lean implementation. Lean promoted planning everything ahead and checking for possible problems to eliminate surprises caused from unexpected problems. It was responsible for a smooth and stable workflow, plus improved project field productivity and work performance. Lean finds and removes constraints prior to the start of work, and helps the owner follow project

progress. It should also provide better problem-solving and effective trouble-shooting.

5. Lean construction should facilitate better matching of labor, materials and equipment to project requirements. It can also prevent overcrowding and interference in the work place.

5.2.2 Perceptive Weaknesses

The barriers to lean implementation are discussed below.

1. Many believed that there were too many meetings and too much information that had to be discussed in the meeting. The meetings were too repetitive, and took a long time if not well-managed. At the meeting it was sometimes difficult if too much detail was explained to the other trades or the owner.
2. The subcontractors could reduce the effectiveness of the general contractor with inaccurate planning and PPC. It was also shown to be difficult to qualify and assign proper subcontractors to a project if they had little background in lean construction. Lean implementation was too dependent upon the quality and attitude of the subcontractors, and depended on participants' keeping promises and being truthful.
3. Lean construction may be beneficial to complex and large projects, but does not easily work for small, simple and easy projects.
4. Lean demands extra paper work and time for training and meetings. Often an extra person was needed who handled lean issues.
5. Lean implementation was too oriented to computer work and to the spontaneous participation of all trades. Without a mandatory clause in the

contract, there were no means to enforce all trades to get involved in lean implementation.

6. Finally, it was not easy to track tasks between all the planning forms.

5.2.3 Perceptive Requirements

Opportunities for the improvement of lean implementation include developing honesty and trust among project participants, increasing upper level management's checking of the planning and performance progress of subcontractors, and increasing the designer's involvement in project.

The requirements for good lean implementation are education and a contract that requires full implementation of lean construction. Upper level management's involvement and assistance is beneficial for better coordination and open-communication.

Lean should work better on the project that provides full information, complete design, and complete submittals from the owner and the architectural engineer.

Chapter 6: Conclusions, Opportunities for Improvement, Recommendations for Future Study, and Contributions

The research model, developed in Chapter 3, was structured to illuminate the relationship between lean planning systems and three other factors: the organizational factor, the contractual factor and participant attitudes. These factors exert various influences on lean implementation. This study assumes that if these factors are mutually and effectively combined, then lean construction can be successfully implemented. The paper further studied the combined four criteria that should contribute to the best results in lean implementation. Figure 6.1 illustrates the relationship among the four criteria.

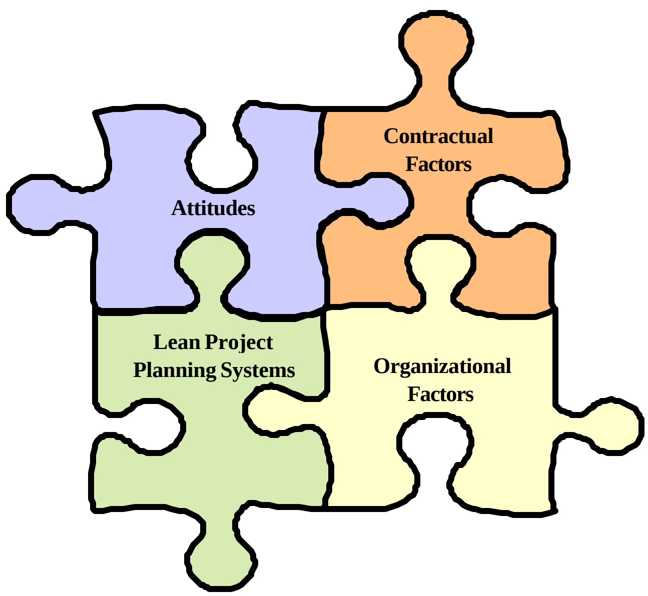

Figure 6.1. Relationship among Four Criteria

6.1 SUMMARY

Most research on lean construction has focused on developing lean theories and tools, and applied these to the process of each construction activity, not to the overall project, to verify and improve instrumental rationality and technical efficiency. Furthermore, the research has ignored considering the human factor and other necessities that are fundamental in implementing lean construction. Thus, this study focuses on essential lean tools, assesses the effects of lean construction on human resources in connection with implementation, and evaluates company project strategies as well.

In conclusion, the study found that lean construction was efficient in managing projects by using lean tools, and improved other project success factors associated with project completion. The success factors were better communication, effective coordination, increased involvement and commitment, trust, and better motivation. Lean construction emphasized and focused on improvement of relationships among project participants. Even though lean construction still stands on the bridge crossing from current practice to lean practice, it is the researcher's conviction that lean construction will be successfully adapted to the construction industry in the near future and will be recognized as an effective management innovation.

6.2 CONCLUSIONS

The following are the conclusions drawn from the lean construction assessment:

1. Lean construction has initially a major influence on improvement of communication and coordination between the owner and general contractor, the general contractor and subcontractors, and among subcontractors. It is one of the fundamental roles of the last planner system. The participants share each other's information, identify which constraints exist from each part, and discuss what each part has to do for others and needs to obtain from others to complete the work; then, they can utilize smoother work flow.

2. Weekly lean meetings are extremely crucial to deliver the most optimized planning and scheduling based on communication and coordination among the participants and to develop involvement and commitment of subcontractors. This weekly lean meeting is mandatory to attend and allows each participant to know what others are going to do. Weekly lean meetings also provide proper work sequence which is coordinated by the project participants. Materials, equipment, laborers and tools can be properly matched to the each task in time and in the proper sequence. Less rework, less change of work priority, less interference between trades, better working conditions, and better productivity should be achieved as results of effective weekly lean meeting.

3. Lean pull schedule also encourages all participants to be involved in the schedule, and to develop the most optimized schedule for all. This scheduling process strongly ties the project participants together and improves team building. The subcontractors are a major constituent in lean construction, and their

involvement and commitment are crucial for successful lean implementation. Lean construction lets the subcontractors have responsibility to plan and schedule their own tasks, to be involved in coordinating their schedules together with the general contractor and other subcontractors, and to refuse unreasonable work assignments scheduled by the general contractor if the assignment cannot be matched to quality criteria. The subcontractors consider not only each trade's own tasks but also another trade's tasks to complete the planned work together. The project is no longer just the general contractor's project. It becomes a collaborated project of all project participants.

4. Metrics to calculate the PPC and to analyze root causes are one of benefits which can be obtained during implementing lean construction. Whenever calculating the PPC, the participants must identify the root causes of failure to complete planned work. The subcontractors must perform corrective action to the root causes identified every week, and the general contractor must request the feedback related to this corrective actions from the subcontractors. However, most current projects fail to effectively implement root cause analysis. Implementing suggestions to reduce root cause failures are difficult to indicate and it appears that many of the project participants do not understand the importance of root cause analysis.

5. Lean construction improves human relationships if effectively implemented. Lean construction involves everyone in the organization. Lean construction crosses all organizational boundaries and is a key component of the corporate strategy. Roles and responsibilities are defined throughout all levels of the organization. Project participants create a shared vision of project objectives for

the project. Good relationships among the project participants will create trust, friendship and respect for each other. Supervision can have fun working on the project while sharing their tools, materials and equipment. The project participants try to keep the promise to complete planned work in the proper sequence to reduce the interference of another trade's work.

6. Company strategies such as company policy, HRM policy, and contract agreements are important to create an environment receptive to lean implementation. Supportive company strategies will improve the organizational relationships, and attitudes of the project participants toward lean construction. Mandatory contract agreements to require lean employment should be made at the start of project among the project participants including the owner and preferably, the engineer.

7. Lean construction should be a manageable work package that may be combined with the tools such as CPM that are already used in the industry to obtain better management and a well-run job. However, this kind of mandatory and systematic work package can be more useful and effective to maintain project performance compared to the traditional project management without any mandatory planning process.

6.3 CONTRIBUTIONS OF THE STUDY

This study makes the following contributions:

1. This exploratory research of lean construction employed independent case studies to assess the benefits of this new approach to project management. It is also a first empirical study of the lean implementation on projects. It is not

oriented to lean theories and technologies and not based on individual construction activities.

2. This study is anticipated to be a framework or a benchmark for future studies in the academic field and for future projects employing lean construction in the construction industry. From the case studies, companies that want to employ lean construction should examine cases A and G. For future lean construction studies, researchers can recognize the current lean implementation stage and refer to these observations to assess and analyze lean construction. Questionnaires developed for this study could be used for other studies.

3. This study is anticipated to share beneficial information for successful lean implementation among construction companies. Companies that are interested in lean construction, but do not know how to start, can examine the case studies. Companies can evaluate how other companies (or projects) have implemented lean construction by examining the case studies.

4. This study provides empirically identified benefits and barriers associated with lean implementation on the construction site. Companies may be more confident and willing to encourage their employees to employ lean construction after reviewing the benefits of lean construction for the case studies.

5. This study promotes the benefits of lean construction team building by more effective planning of activities of the workforce. Companies will find how lean construction improved team building.

6. This study indicates different levels of lean implementation yet all the projects were benefiting from the upper-level planning and completing work in sequence.

6.4 RECOMMENDATIONS

Based on the findings of this study, the following recommendations are offered to support the effort of continuous lean construction improvement.

6.4.1 Recommendations for Implementation

1. Lean training programs need to be developed for subcontractors. If it is difficult to provide training to subcontractors, it would be effective to assign at least one lean-experienced subcontractor to guide and help other subcontractors implement lean construction. Lean concepts and principles may be complex for the subcontractors to understand, but training can focus on lean implementation: the "how-to", rather than on lean theories. In addition, the company should make their own lean manuals for the project team and subcontractors. The lean manual can guide how to conduct lean construction work planning meetings and establish the forms of lean planning systems.
2. Project problems occurred with activities where the subcontractor's planning was weak and involvement was lacking, thus the subcontractor's lookahead schedule was not detailed enough. To prevent these problems in the future, management patience and persistence at enforcing consistency of practice at every level of the organization is required. Also, the general contractor needs to consistently require the weekly lookahead reviews and help the subcontractors with the lookahead schedules.
3. The owner and general contractor can hire a lean manager or facilitator to support and sustain the effort to implement lean construction. He/she can more effectively help the general contractor project team and subcontractors establish

all aspects of lean at the beginning of the project and can implement lean construction in the construction field. The facilitator can reduce the project engineers' lean work load.

4. It is important to note that the previous recommendations may result in a more effective lean construction project. However, many of the case studies indicated that the contractors failed to implement many of the lean construction techniques yet they were receiving the benefits of better planned work activities when compared to other projects. Thus, the contractors are encouraged to begin to employ the lean construction techniques without going through all the changes at once rather than considering this approach is too radically different not to be considered on their projects.

6.4.2 Recommendations for Future Study

1. A large database of projects employing lean principles should be developed. CII is beginning to evaluate lean construction projects.

2. Simple software development is recommended to create standard forms for the lean planning systems and to make it easy to update the schedule and obtain feedback. Project participants can then easily track each task between the lean planning forms. The software can allocate task durations and modify the schedule automatically according to the completion of activities.

3. Research on company strategies such as contractual agreements, HRM policy, and company policy to reinforce lean implementation deserves to be studied.

4. The LCI is applying lean ideas to design, and anticipates finding more opportunities for improvement in the design team's commitment to a lean project.

5. Research to determine how to utilize the talent and knowledge of human resources to encourage learning and continuous improvement and how to maintain lean-experienced employees and subcontractors from a previous project to a new project is recommended. Research on lean construction related to Tier II should reinforce lean implementation by empowering the last executive level of organization.

Appendix A

Simple Questionnaire and Interview Outlines

GC's Evaluation

Interviewee:

1. **Managerial Time & Attention:** Compared to other similar projects, how was the managerial time and attention consumed on this project?

1	2	3	4	5
much less	somewhat less	about the same	somewhat more	much more

2. **Job Satisfaction:** Compared to other similar projects, what was the level of job satisfaction on this project?

1	2	3	4	5
much worse	somewhat worse	about the same	somewhat better	much better

3. **Turnover & Absenteeism:** Compared to other similar projects, how was the turnover and absenteeism on this project?

1	2	3	4	5
much less	somewhat less	about the same	somewhat more	much more

4. **Competitiveness:** Do you think the company that employs lean construction is more competitive in the construction market compared to companies not employing lean construction?

1	2	3	4	5
much worse	somewhat worse	about the same	somewhat better	much better

Specialties' Evaluation

Interviewee:

1. Planning & Coordination: Compared to other similar projects, how was the planning and coordination on this project?

1	2	3	4	5
much worse	somewhat worse	about the same	somewhat better	much better

2. Involvement & Commitment: Compared to other similar projects, how was the involvement and commitment of specialties on this project?

1	2	3	4	5
much worse	somewhat worse	about the same	somewhat better	much better

3. Fire-fighting: Compared to other similar projects, how many unexpected and urgent problems have been experienced on this lean project?

1	2	3	4	5
much less	somewhat less	about the same	somewhat more	much more

4. Productivity: Compared to other similar projects, how was the productivity on this project?

1	2	3	4	5
much worse	somewhat worse	about the same	somewhat better	much better

5. Unplanned overtime (OT): Compared to other similar projects, how was the unplanned OT on this project?

1	2	3	4	5
much less	somewhat less	about the same	somewhat more	much more

6. Job Satisfaction: Compared to other similar projects, what was the level of job satisfaction on this project?

1	2	3	4	5
much worse	somewhat worse	about the same	somewhat better	much better

7. **Rework:** Compared to other similar projects, how was the rework due to common problems (design changes, priority order and prerequisite work) on this project?

1	2	3	4	5
much less	somewhat less	about the same	somewhat more	much more

8. **Resources Availability:** Compared to other similar projects, assess the resources availability (materials, tools, equipment and information) on this project?

1	2	3	4	5
much worse	somewhat worse	about the same	somewhat better	much better

9. **Working Conditions:** Compared to other similar projects, assess the working conditions (over-crowed work area, crew interference and stacking of trades) on this project?

1	2	3	4	5
much worse	somewhat worse	about the same	somewhat better	much better

10. **Wasted Time:** Compared to other similar projects, assess the wasted time (waiting and idle time) on this project?

1	2	3	4	5
much less	somewhat less	about the same	somewhat more	much more

11. **Work Assignments:** Compared to other similar projects, assess the work assignments (definition, size, sequence and soundness) on this project?

1	2	3	4	5
much worse	somewhat worse	about the same	somewhat better	much better

Project Manager

1. Project Scope:

2. What is the approximate construction cost of this project?

   - Budgeted vs. Actual

3. Is the project on schedule at this time?

   - Scheduled vs. Actual

4. How is the organization of this project?

   - Workers' Status: Union ____ Open-shop ____ Mixed ____
   - In-house Staff
   - Key Subcontractors

5. Which lean systems are used for your project? Master Pull Scheduling _____
   Phase Scheduling _____
   Lookahead Planning _____
   Weekly Work Planning _____
   Supply Chain (JIT) ______

6. Meetings

   - What kind of meetings (related to lean or others)
   - When / How often / With whom
   - Meeting hours consumed
   - Difficulties vs. Benefits

7. Training (copy of training program?)

   - When / How often / With whom
   - Difficulties vs. Benefits

8. Planning and scheduling (copy of results?)

   - PPC results
   - Root cause analysis of reasons
   (What were the main reasons for planning failure?)
   (What were the main reasons for failure of completing planed work?)
   - Difficulties vs. Benefits

9. Attitudes toward the lean construction

- Owner:
- GC (especially the highest level):
- Designer:
- Subcontract Company (Difficulties to utilize the project relative with other projects, Work priorities):
- Supplier (More deliveries with smaller amount of materials, Reliable promise):
- Difficulties vs. Benefits

10. Compared to the traditional construction, what benefit is the lean construction technique? (Is there anything new?)

11. Lean production has been accepted as one of critical issues in manufacturing industry. Do you agree that it is also important in the construction industry?

12. Have you utilized the current planning and control system – CPM and Earned Value – as well as lean system of measuring progress?

13. What are the key factors for successful lean implementation?

For instance,
Training _____
Planning _____
Foremen (sub-cons) abilities _____
Work Experience _____
Involvement and commitment _____
Coordination and communication _____
Change of organizational culture (e.g. Bureaucracy, a power culture) _____
Supply management _____

14. Please assess the overall lean construction.

- How well is the lean construction working on this project?
- Difficulties and benefits
- What are the major differences between this lean construction project and a traditional project?
- Recommendations

Key Specialties PM and Foremen

1. Training

- When / By whom
- Effective and useful?
- Did you learn anything new?
- Difficulties vs. Benefits

2. Meetings

- What kind of meetings
- When / How often / With whom
- Meeting hours consumed
- Difficulties vs. Benefits

3. Planning and scheduling

- Planning Reliability
- Coordination & Communication
- Root cause analysis of reasons
  (What were the main reasons for planning failure?)
  (What were the main reasons for failure of completing planed work?)
- Difficulties vs. Benefits

4. Work Assignments

- Who actually makes work assignments in the WWP meeting?
  1) Are foremen directed by the project manager or others?
  2) Are foremen actually involved in making assignment?
- Do you have difficulty saying 'No' to poor assignments?
- Is it comfortable for you to make work assignments?
- Is there any review by management, supervisor or engineer of the planned work assignments?

5. What do think about the measurement of 'Percent Plan Complete' method comparing to the productivity measurement?

6. Compared to the traditional construction, what is different about a lean construction project?

7. Lean production has been accepted as one of critical issues in manufacturing industry. Do you agree that it is also important in the construction industry?

8. What are the key factors for successful lean implementation?

For instance,
Training _____
Planning _____
Foremen (specialties) abilities _____
Work Experience _____
Involvement and commitment _____
Coordination and communication _____
Change of organizational culture (e.g. Bureaucracy, a power culture) _____
Supply management _____

10. Please assess the overall lean construction.

- How well is the lean construction working on this project?
- Difficulties and benefits
- What are the major differences between this lean and traditional?
- Recommendations

Appendix B

Sample forms of Lookahead, Lookahead-constraints analysis, Weekly Work Plan & PPC

Project Name: **Last Planner - Lookahead Constraints Analysis**

Prepared By: **Run Date:**

Act. ID	Activity Description	Planned Start Date	Responsible Party	Contract/ Change Orders	Design			Materials	Labor	Equipment	Prerequisite Work	Space	Sound?
					AE Complete	Submittals	RFIs						

6 Week Lookahead Schedule

Act. ID	Activity	Week Ending					Week Ending					Week Ending					Week Ending					Week Ending					Week Ending					Needs
		M	T	W	Th	F	M	T	W	Th	F	M	T	W	Th	F	M	T	W	Th	F	M	T	W	Th	F	M	T	W	Th	F	

Project: **Weekly Work Plan & PPC** **Crew Size:**

Foreman:

Date:

Act. ID	Activity	Make Ready Needs	Est	Act	Mon	Tue	Wed	Thur	Fri	Sat	Sun	Done?		PPC	Reason for Variances
												Y	N		

Appendix C

Samples of Six-week lookahead, Two-week lookahead, Construction Planner, and PPC chart prepared by one of subcontractors' foremen in the case study projects

6 Week Sch

Prepared By

All Jobs	Week 1		3-Dec					Week 2		10-Dec					Week 3		17-Dec				
Task	Mon	Tue	Wed	Thurs	Fri	Sat	Sun	Mon	Tue	Wed	Thurs	Fri	Sat	Sun	Mon	Tue	Wed	Thurs	Fri	Sat	Sun
Install sleeves& hangers	X	X	X	X	X			X	X	X	X	X			X	X	X	X	X		
O2 line	X	X	X	X	X			X	X	X	X										
Gas line								X	X	X	X										
Decontamination Tank											X	X			X	X					
Material take off	X	X	X	X	X			X	X	X	X	X			X	X	X	X	X		
Storm underground area 1			X	X	X			X	X	X	X	X									

6 Week Sch   Prepared By

All Jobs	Week 4		24-Dec					Week 5		31-Dec					Week 6		7-Jan				
Task	Mon	Tue	Wed	Thurs	Fri	Sat	Sun	Mon	Tue	Wed	Thurs	Fri	Sat	Sun	Mon	Tue	Wed	Thurs	Fri	Sat	Sun
Install sleeves& hangers			X	X	X			X	X	X	X	X			X	X	X	X	X		
Underground area 1			X	X	X			X	X	X	X	X			X	X	X	X	X		
rough in															X	X	X	X	X		
Material take off			X	X	X			X	X	X	X	X			X	X	X	X	X		

Two Week look ahead schedule **Prepared by**

Task	Make Ready Needs	Mon	Tue	Wed	Thu	Fri	Sat	Sun
		Week 1				3-Dec-01		
Set sleeves for 2nd floor area 2	Acess two 2nd Floor	2men	2men	2men	2men	2men		
set carrires 1st floor area 2		1Man	1Man	1Man	1Man	1Man		
install hanger rods 2nd floor area 2	Acess to 2nd floor	2men	2men	2men	2men	2men		
Layout 1st floor area 2		2men	2men	2men	2men	2men		
O2 Line	Pipe & manpower	2men	2men	2men	2men	2men		
storm underground area 1	Man power			5Men	5Men	5Men		
Workable backlog								
Prefab sink risers								
Replace & Repair underground plumbing								

Task	Make Ready Needs	Mon.	Tue.	Wed.	Thur.	Fri	Sat.	Sun.
		Week 2				10-Dec-01		
Gas Main	Material & equip	2men	2men	2men	2men	2men		
set carrires 1st floor area 2		1Man	1Man	1Man	1Man	1Man		
install hanger rods 2nd floor area 3	Deck in place			2men	2men	2men		
Layout 1st floor area 2		2men	2men	2men	2men	2men		
O2 Line		2men	2men	2men	2men			
storm underground area 1		5Men	5Men	5Men				
Decontamination tank	Tank				2Men	2Men		
Workable backlog								
Prefab sink risers								
Replace & Repair underground plumbing								

Prepared By

Construction Planner

ID#	Task	Start	Contract	Design	Submittals	Materials	Pre-Requisite	Space	Equipment	Labor	Other	Comments /Delay reasons
	O2 Line	3-Dec	Yes	yes	Yes	yes	Location of south east corner bulk storage	yes	Yes	Yes		
	Gas line	10-Dec	Yes	yes	no	No	Location from Linbeck	Yes	Yes	Yes		
	Sleeves 2nd floor area 3	13-Dec	Yes	Yes	Yes	No	Manpower & drawings	Yes	Yes	Yes		
	Decontamination tank	14-Dec	Yes	yes	no	no	Order tank	Yes	yes	yes		
	Roof drains	10-Dec	Yes	yes	no	no	Need roof drains	yes	Yes	no		
	Area 1 underground	24-Dec	Yes	NO	YES	NO	Need drawing of changes & Spread footings in place	yes	Yes	no		
	Building roughin 1st floor area 2	28-Nov	Yes	No	No	No	2nd Floor in place submitals	yes	no	no		
	Carriers 1st floor Aera 2	28-Nov	Yes	yes	No	Yes	Material	yes	Yes	Yes		
	Layout water & medgas 1st floor area 2	19-Nov	Yes	yes	Yes	Yes	Decking in place above	yes	Yes	Yes		
	Hanger rods area 2	29-Nov	Yes	yes	Yes	Yes	Manpower	yes	Yes	Yes		

PPC Chart

Prepared by

		Week 1				19-Nov-01				
Task	Make Ready Needs	Mon	Tue	Wed	Thu	Fri	Sat	Sun	PPC	Comment & reason for delay
Set sleeves for 2nd floor area 2	Acess to 2nd floor	2Men	2Men	2Men	2Men	2Men			No	Rain & manpower
Layout 1st floor area 2	Decking above	2men	2men	2men	2men	2men			No	Yes
set carrires 1st floor area 2					1Man	1Man			No	Rain & manpower
install hanger rods 2nd floor area 2	Acess to 2nd floor				1Man	1Man			No	Rain & manpower
Workable backlog										
Prefab Sink risers									Yes	

Appendix D

5S Audit Checklist, Logistics Planning Checklist/Consideration, and Project Production Control Checklist

5S AUDIT CHECKLIST

Company Name:

Contract Number:

Project Name/ No.:

Completed By:

CHECK ALL AREAS REVIEWING

	Office Trailer Area
	Break Area/Change Trailers
	Bone Yard/Storage Area
	Bldg Work Area Perimeter
	Immediate Work Area

Date:

Answer the following questions by marking the appropriate box with either Agree, Disagree or N.A. (Not Applicable).

Disagree needs to be addressed with an action plan.

5S		QUESTION	AGREE	DISAGREE	N. A.	COMMENTS / ACTION PLAN	DUE	CLOSE
STANDARDIZE	1	Has a Logistics Plan been developed?						
	2	Are 5S assessments done on a regular basis?						
	3	Are 5S expectations communicated regularly?						
	4	Is the 5S Audit Checklist being followed?						
	5	Are Action Plans being completed on time?						
SYSTEMATIZE	1	Has 5S been communicated & reviewed before work starts?						
	2	Is 5S & Logistics Plan being implemented?						
	3	Has jobsite personnel been trained in 5S & Logistics Plan?						
	4	Is 5S & Logistics Plan adaptable to changing conditions?						
	5	Is the 5S & Logistics Plan effective?						
SEPARATE & SCRAP	1	Is there a Logistics Plan for the area?						
	2	Is debris separated from good material?						
	3	Is debris disposed of in appropriate receptacles?						
	4	Are there sufficient waste receptacles/dumpsters provided?						
	5	Is area free of excessive material?						
STRAIGHTEN	1	Is the Logistics Plan being followed?						
	2	Is area organized & consolidated?						
	3	Are materials, tools & equipment stored neatly?						
	4	Are materials, tools & equipment readily accessible?						
	5	Are materials, tools & equipment NOT interfering with work efforts?						
SCRUB / SWEEP	1	Are traffic areas clear & maintained?						
	2	Are trash receptacles being utilized & maintained?						
	3	Is area sufficiently cleaned for following trades?						
	4	Is finished product being protected from ongoing work?						
	5	Are finished surfaces cleaned?						

WA Approval: **Date:**

Walbridge Aldinger **Lean Practices & Principles**

COMMITMENT TO EXCELLENCE

Project Name/Job No. ____________________

Logistics Planning Checklist/Considerations

Date

Description of Consideration	Date/ Initials	Comments
1. Owner and Contract requirements		
2. Project Quality Requirements		
A. 5-S Planning		
B. WA ISO requirements (job site quality plan)		
3. Permitting and Governmental Requirements		
A. Traffic – Access/Egress (safe & solid)		
B. Emergency – Access/Egress (safe & solid)		
C. Soil Erosion		
D. Signage/ Job Site Information Center		
E. Meters – water, etc.		
4. Shift Changes and Owner's Work Schedule		
5. WA Trailer City		
A. Project Boundaries (layout & easements)		
B. Utilities (both permanent and temporary)		
C. Parking (on and off site)		
D. Security - (fencing)		
6. Environmental		
A. Fuel Storage		
B. Special containment (liquids/materials)		
C. Recycling (sorting)		
7. Work Flow & Sequence Plan(s)		
A. Direction of construction		
1. Pre-shell and Post-shell		
2. Special construction means and methods		
3. Schedule to reflect direction		
4. Control of Site water		
B. Weather Impact (historical data)		
C. Dumpsters, trash chute locations and trash barrels		
D. Toilet Facilities		
E. Lay Down Area/ Bone Yard/ Sub's Trailers		
F. Parking		
G. Delivery Methods (consider Just-In-Time delivery against work conditions & schedule)		
8. Other considerations (optional)		

Project Production Control Checklist Survey

QUESTIONS	ANSWERS
1. How often is the project **master schedule** updated? (Never, by phase, monthly? More often?)	
2. Is the **master schedule** divided into phases?	Yes or No
3. Are **phase schedules** developed in a team setting that involves subcontractors?	Yes or No
4. Is the **phase schedule** updated weekly and revised if necessary?	Yes or No
5. Is a **look-ahead schedule** maintained, with one week added each week?	Yes or No
6. How many weeks are included in your **look-ahead schedule**?	
7. Are subcontractors requested each week to provide status information regarding **constraints** on the activities listed on the project look-ahead schedule?	Yes or No
8. Are **make-ready actions** assigned each week?	Yes or No
9. To whom are **make-ready actions** assigned? -general contractor personnel (yes or no) -subcontractors (yes or no) -client representatives (yes or no) -design team (yes or no)	 Yes or No Yes or No Yes or No Yes or No
10. If **make-ready actions** are assigned, is it done verbally or in writing?	Verbal / Written
11. Is a copy of the **assignments** in the look-ahead window sent to each subcontractor project manager each week with a request to update **constraint** status?	Yes or No
12. A) Do you try to follow the rule that activities keep their scheduled dates only if the planner is confident they can be **made ready** in time? B) When, if ever, do you allow exceptions to this rule? (Answer B below.)	Yes or No
13. Is your **PPC-2** rising or falling?	Rising / Falling
14. Is your **PAA-2** rising or falling?	Rising / Falling
15. Do you try to follow the rule: Allow into weekly work plans only activities that have had all constraints removed that could be removed before the start of the plan week?	Yes or No
16. When, if ever, do you allow activities onto weekly work plans that have not had all constraints removed that could have been removed before the start of the plan week? (If allowed, explain below.)	Allow / Don't Allow

Project Production Control Checklist Survey (Continued)

17. Are **weekly work plan** forms completed each week?	Yes or No
18. Do **weekly work plans** include make ready needs?	Yes or No
19. Do **weekly work plans** include workable backlog?	Yes or No
20. Are **weekly work plan** assignments adequately defined; e.g., is the work to be completed during the week specified?	Yes or No
21. Are weekly work plans used in the field; e.g., does every superintendent carry it with them?	
22. Does the project hold **weekly subcontractor coordinating meetings**?	Yes or No
23. Are **weekly work plans** reviewed in the coordinating meetings, PPC calculated, and reasons identified?	Yes or No
24. Is your **PPC-1** rising or falling?	Rising / Falling
25. Is your **PAA-1** rising or falling?	Rising / Falling
26. Is there always (or at least periodically) an analysis of selected reasons to **root causes** and assignment or request for corrective action?	Yes or No
27. What are the **dominant reasons** for failing to complete assignments on weekly work plans? Reasons:	

Glossary

1. Workable Backlog: assignments that have met all quality criteria, except that some must yet satisfy the sequence criterion by prior execution of prerequisite work already scheduled. Other backlog assignments may be performed within a range of time without interfering with other tasks.

2. Shielding: not releasing work to production units because it does not meet quality criteria; the work is not a quality assignment. It is akin to 'stopping the assembly line. The purpose of shielding is the make production units less subject to uncertainty and variation, thereby providing them with greater opportunity to be reliable.

3. First-Run Study (FRS): trial execution of a process in order to determine the best means, methods, sequencing, etc. to perform it. First-run studies are done a few weeks ahead of the scheduled execution of the process, while there is time to acquire different or additional prerequisites and resources.

4. Throughput: the output rate of a production process.

5. Work-In-Process (WIP): the inventory between the start and end points of a production process.

6. Takt Time: a calculated value based on customer demand. Takt time is the speed at which parts must be manufactured in order to satisfy demand, and it is the heartbeat of any lean system.

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